

R. B. TODD



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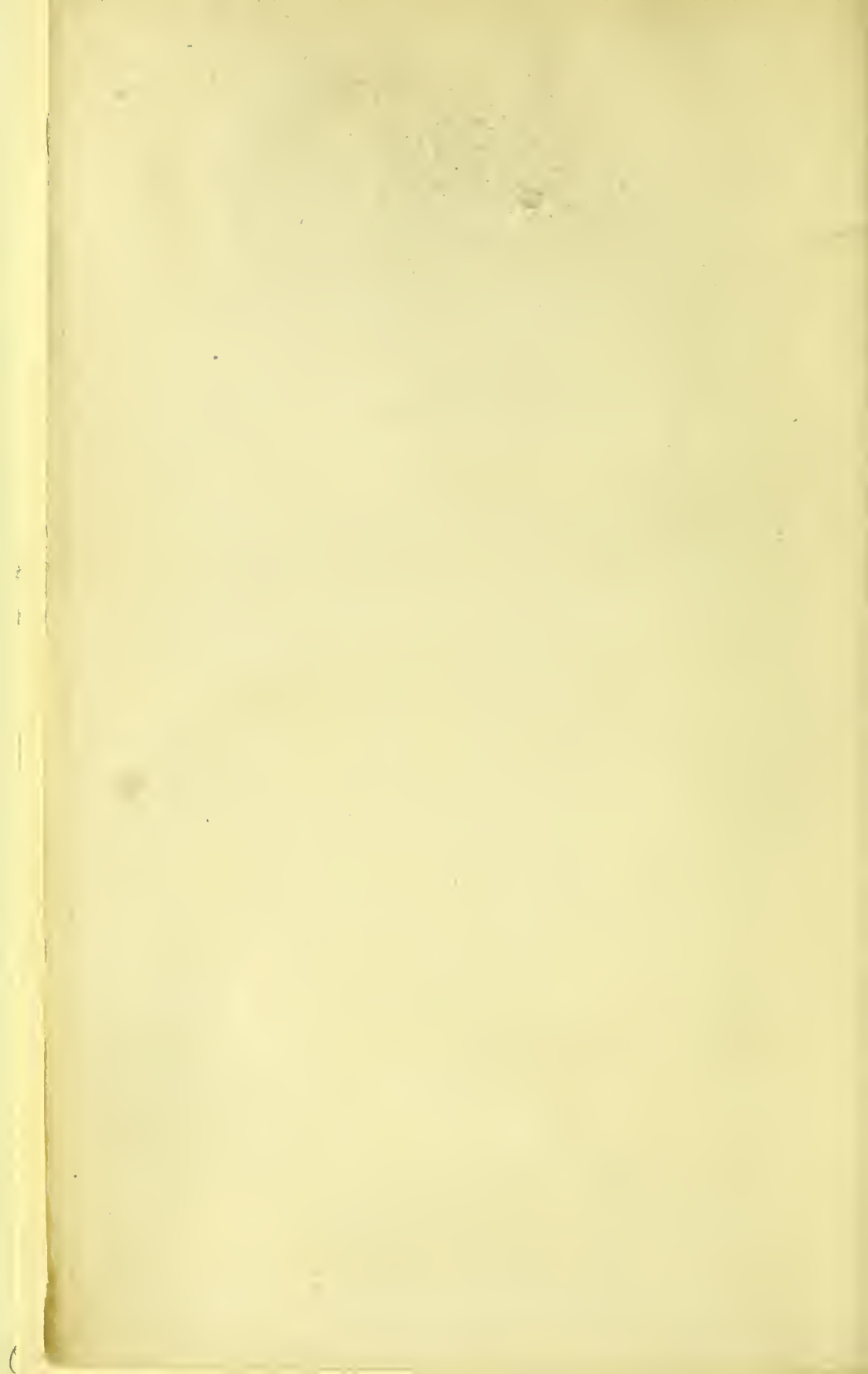


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**ELEMENTS**  
**OF**  
**P H Y S I C S,**  
**OR**  
**NATURAL PHILOSOPHY.**

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**VOL. I.**

## ADVERTISEMENT.

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VOLUME I. of this work contains Treatises on

STATICS,	HYDROSTICS,	ACOUSTICS,
DYNAMICS,	HYDRAULICS,	ANIMAL, and
MECHANICS,	PNEUMATICS,	MEDICAL MECHANICS.

Volume II. Part 1. (now published with this) contains Treatises on  
HEAT, and      LIGHT, or      OPTICS.

Volume II. Part 2. (to be published in May) contains Treatises on  
ELECTRICITY,      MAGNETISM, and ASTRONOMY.

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The description of the Hydrostatic, or Floating Bed, recently contrived by Dr. Arnott for the relief of the bedridden, is at page 581, vol. I.

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In the preceding editions of this work, to shew more completely the relative importance of Physics, the "Introduction," while taking a general view of the progress of knowledge and civilization among mankind, also glanced, slightly, at what "Education," in its widest sense, should be. In the present edition, however, as forty pages of new matter have been added to the body of the work, in a volume already almost too large, and as the author has in progress a work expressly on Education, in which that most important of all subjects, whether to individuals or societies, will be fully treated, he has curtailed a little the present Introduction.

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For non-professional readers, this volume will be complete when the last few leaves, from page 671 to page 692 inclusive, are left out. The binder will take directions accordingly.

ELEMENTS  
OF  
PHYSICS,  
OR  
NATURAL PHILOSOPHY,  
GENERAL AND MEDICAL,  
WRITTEN FOR  
UNIVERSAL USE,  
IN  
PLAIN OR NON-TECHNICAL LANGUAGE,  
AND CONTAINING  
NEW DISQUISITIONS AND PRACTICAL SUGGESTIONS.



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IN TWO VOLUMES.  
VOL. I.

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BY NEIL ARNOTT, M.D.,  
OF THE ROYAL COLLEGE OF PHYSICIANS.

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*Fifth Edition.*

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## INTRODUCTION.

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TO appreciate the importance of PHYSICS or NATURAL PHILOSOPHY, as an object of study not only to all persons engaged in scientific pursuit, but, in the present day, to all who pretend to a moderately good education, we must take a rapid glance at the nature of human knowledge generally, and at its bearings on the existing condition of mankind.

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WHILE the inferior races of animals on earth seem to have changed as little in any respect since the beginning of human records, as the trees and herbs of the thickets which give many of them shelter, the condition of man himself has fluctuated, but, on the whole, progressed in a very remarkable manner. The inferior animals were formed by their Creator such, that within one life or generation they should attain all the perfection of which their nature was susceptible. Their wants were either immediately provided for—as instanced in the clothing of feathers to birds, and of furs to quadrupeds; or were so few and simple, that the supply was easy to very limited powers—except in a few cases where considerable art was required, as by the bee in making its honey-cell, or by the bird in constructing its beautiful nest, and there, a peculiar aptitude or instinct was bestowed. Thus a crocodile which issues from its egg in the warm sand, and never sees its parent, becomes as perfect and knowing as any crocodile that has lived before or that will appear after it.—But how different is the story when we turn to man! He

comes into the world the most helpless of living beings, long to continue so ; and if deserted by parents at an early age, so that he can learn only what the experience of one life may teach him,—as to a few individuals has happened who yet have attained maturity in woods and deserts,—he grows up in some respects inferior to the nobler brutes. Now as regards many regions of the earth, history exhibits the early human inhabitants in states of ignorance and barbarism, not far removed from this lowest possible grade, which civilized men may shudder to contemplate. But these countries, occupied formerly by straggling hordes of miserable savages, who could scarcely defend themselves against the wild beasts that shared the woods with them, and the inclemencies of the weather, and the consequences of want and fatigue, and who to each other were often more dangerous than any wild beasts, unceasingly warring among themselves, and destroying each other with every species of savage, and even cannibal cruelty—countries so occupied formerly, are now become the abodes of myriads of peaceful, civilized, and friendly men, where the desert and impenetrable forest are changed into cultivated fields, rich gardens, and magnificent cities.

It is the strong intellect of man, operating with the faculty of language as a means, which has gradually worked this wonderful change. By language fathers communicated their gathered experience and reflections to their children, and these to succeeding children, with new accumulation ; and when, after many generations, the precious store had grown until simple memory could retain no more, the arts of writing, and then of printing, arose, making language visible and permanent, and enlarging illimitably the repositories of knowledge. Language thus, at the present moment of the world's existence, may be said to bind the whole human race of uncounted millions into one gigantic rational being, whose memory reaches to the beginnings of written records, and retains imperishably the

important events that have occurred; whose judgment analyzing the treasures of memory, has discovered many of the sublime and unchanging laws of nature, and has built on them all the arts of life, and through them, piercing far into futurity, sees clearly many of the events that are to come; and whose eyes and ears and observant mind at this moment, in every corner of the earth, are watching and recording new phenomena, for the purpose of still better comprehending the magnificence and beautiful order of creation, and of more worthily adoring its beneficent Author.

It might be very interesting to shew here, in minute detail, how the arts and civilization have progressed in accordance with the gradual increase of man's knowledge of the universe; but to do so would lead too far from the main subject. We deem it right, however, to make evident to the student the arousing truths, that the progress is not yet at an end; that it has been vastly more rapid in recent times than ever; and that it seems still to proceed with increasing celerity:—and we know not where the Creator has fixed the limits of the change! Although there are thousands of years on the records of the world, our BACON, who first taught the true way to investigate nature, lived but the other day. NEWTON followed him, and illustrated his precepts by the most sublime discoveries which one man has ever made. HARVEY detected the circulation of the blood only two hundred years ago. ADAM SMITH, Dr. BLACK, and JAMES WATT were friends, and the last, whose steam-engines are now changing rapidly the condition of empires, may be said to be scarcely cold in his grave. JOHN HUNTER died not long ago; HERSCHEL's accounts of newly-discovered planets, and of the sublime structure of the heavens, and DAVY's account of chemical discoveries not less important to man, are in the late numbers of our scientific journals;—illustrious Britons these, and who have left worthy successors treading in their steps. On the con-

continent of Europe, during the same period, a corresponding constellation of genius has shone; and LAPLACE was lately the bright star shining between the future and the past.

But there is a change going on in the world, connected closely with the progress of science, yet distinct from it, and more important than a great part of the scientific discoveries;—it is the *diffusion of existing knowledge* among the mass of mankind. Formerly knowledge was shut up in convents and universities, and in books written in the dead languages—or in books which, if in the living languages, were so abstruse and artificial, that only a few persons had access to their meaning; and thus, the human race being considered as one great intellectual creature, a small fraction only of its intellect was allowed to come into contact with science, and therefore into activity. The progress of science in those times was correspondingly slow, and the evils of general ignorance prevailed. Now, however, the strong barriers which confined the stores of wisdom have been thrown down, and a flood is overspreading the earth; old establishments are adapting themselves to the spirit of the age; new establishments are arising; the inferior schools are introducing improved systems of instruction; and good books are rendering every man's fireside a school. From all these causes there is growing up an *enlightened public opinion*, which quickens and directs the progress of every art and science, and through the medium of a free press, although overlooked by many, is now rapidly becoming the governing influence in all the affairs of man. In Great Britain, partly perhaps as a consequence of its insular situation, which lessened among its inhabitants the dread of hostile invasion, and sooner formed them into a united and compact people, the progress of enlightened public opinion had been more decided than in any other state. The early consequences were more free political institutions; and these gradually led to greater and

greater improvements, until Britain became an object of admiration among the nations. A colony of her children, imbued with her spirit, now occupies a magnificent territory in the new world of Columbus; and although it has been independent as yet for only half a century, it already counts more people than Spain, and will soon be second to no nation on earth. The example of the Anglo-Americans has aided in rendering their western hemisphere the cradle of many other gigantic states, all free, and following, although at a distance, the like steps. In the still more recently discovered continent of Australasia, which is nearly as large as Europe, and is empty of men, colonization is spreading with a rapidity never before witnessed; and that beautiful and rich portion of the earth will also soon be covered with the descendants of free-born and enlightened Englishmen. From thence, still onward, they or their institutions will naturally spread over the vast archipelago of the Pacific Ocean, a track studded with islands of paradise. Such, then, is the extraordinary moment of revolution or transit, in which the world at present exists! And where, we may ask again, has the Creator predestined that the progress shall cease? Thus far at least we know, that he has made our hearts rejoice to see the world filling with happy human beings, and to observe that the increase of the sciences can make the same spot maintain thousands in comfort and godlike elevation of mind, where with ignorance even hundreds had found but a scanty and degrading supply.

The progress of knowledge which has thus led from former barbarism to present civilization, has gone on by certain remarkable steps, which it is easy to point out; and which it is very useful to consider, because we thereby discover the nature of human knowledge, with the relations and importance of its different branches; and we obtain great facilities for studying science, and for quickening its farther progress.



The human mind, when originally directed to the almost infinity of objects in the universe around it, must soon have discovered that there were resemblances among them ; in other words, that the infinity was only a repetition of a certain number of kinds. Among animals, for instance, it would distinguish the sheep, the dog, the horse ; among vegetables, the oak, the beech, the pine ; among minerals, lime, flint, the metals, and so forth. And becoming aware that by studying an exemplar of each kind, its limited power of memory might acquire a tolerably correct knowledge of the whole, while this knowledge would enable the possessors more easily to obtain what was useful to them, and to avoid what was hurtful, the desire for such knowledge must have arisen with the first exercise of reason. Accordingly, the pursuit of it has been unremitting, and the labour of ages has at last nearly completed an arrangement of the constituent materials of the universe, under three great classes of MINERALS, VEGETABLES, and ANIMALS; commonly called the *three kingdoms of Nature*, and of which the minute description is termed NATURAL HISTORY : and museums of natural history have been formed which contain a specimen of almost every object included in these classes, so that now, a student, within the limits of an ordinary garden, may be said to be able to examine the whole of the material universe.

While men were examining the *forms* and other qualities of the bodies around them, they could not avoid noticing also the *motions* or changes going on among bodies ; and here, too, they would soon make the grand discovery, that there were resemblances in the multitude. Self-interest, as in the case of the bodies themselves, having prompted to careful classification, in the present day, as the result of countless observations and experiments made through the series of ages, we are enabled to say, that all the *motions*, or *changes*, or *phenomena* (words synonymous here) of the universe, are merely a repetition and mixture of a few simple

manners or kinds of motion or change, which are as constant and regular in every case, as where they produce the returns of day and night, and of the seasons. All these phenomena are referable to four distinct classes, which we call *Physical, Chemical, Vital, and Mental*. The simple expressions which describe them are denominated *General Truths* or *Laws of Nature*, and as a body of knowledge, they constitute what is called SCIENCE or PHILOSOPHY, in contradistinction to NATURAL HISTORY, already described. Now as man cannot, independently of a supernatural revelation, learn any thing but what respects, 1st. the momentary state, past or present, of himself and the objects around him; and 2d. the manner in which the states have changed: *Natural History* and *Science*, in the sense now explained, make up the whole sum of his knowledge of nature.

To exemplify the process by which a general truth or law of nature is discovered, we shall take the physical law of *gravity* or *attraction*. 1st. It was observed that bodies in general, if raised from the earth, and left unsupported, fell towards it; while flame, smoke, vapours, &c., if left free, ascended away from the earth. It was held, therefore, to be a very general law, that things had *weight*; but that there were exceptions in such matters as now mentioned, which were in their nature *light* or ascending. 2d. It was discovered that our globe of earth is surrounded by an ocean of air, having nearly fifty miles of altitude or depth, and of which a cubic foot, taken near the surface of the earth, weighs about an ounce. It was then perceived that flame, smoke, vapour, &c. rise in the air only as oil rises in water, *viz.* because not so heavy as the fluid by which they are surrounded: it followed, therefore, that nothing was known on earth naturally *light*, in the ancient sense of the word. 3d. It was found that bodies floating in water, near to each other, approached and feebly cohered; that any contiguous hanging bodies were drawn towards each other, so as not to hang quite perpendicularly; and

that a plummet suspended near a hill was drawn towards the hill with force only so much less than that with which it was drawn towards the earth, *viz.* the weight of the plummet, as the hill was smaller than the earth. It was then proved that weight itself is only an instance of a more general *mutual attraction*, operating between all the constituent elements of this globe; and which explains, moreover, the fact of the rotundity of the globe, all the parts being drawn towards a common centre, as also the form of dew-drops, rain-drops, globules of mercury, and of many other things; which, still further, is the reason why the distinct particles of which any solid mass, as a stone or piece of metal, is composed, cling together as a mass, but which, when overcome by the repulsion of heat, allows the same particles to assume the form of a liquid or air. 4th. It was farther observed, that all the heavenly bodies are round, and must, therefore, consist of material obeying the same law. 5th. And lastly, that these bodies, however distant, attract each other; for that the tides of our ocean rise in obedience to the attraction of the moon, and become *high* or *spring-tides*, when the moon and sun operate in the same direction. Thus the sublime truth was at last made evident, and by the genius of the immortal Newton, that there is a power of attraction connecting together the bodies of this solar system at least, and probably limited only by the bounds of the universe.

Acquaintance with the laws of nature has been very slowly obtained, owing to that complexity of ordinary phenomena, which is produced by several laws operating together, and under great variety of circumstance. With respect to many laws of Chemistry and Life, men seem to be yet little further advanced than they were with respect to the physical law of *attraction*, when they knew only that heavy things fell to the earth. But we have learned enough to perceive that the great universe is as simple and harmonious as it is immense; and that the Creator, instead of



interposing separately, or miraculously, in the common sense of the word, to produce every distinct phenomenon, has willed that all should proceed according to a few general laws. There is nothing in nature so truly miraculous and adorable as that the endless and beneficent variety of results which we see, should spring from such simple elements. In times of ignorance men naturally regarded every occurrence which they did not understand, that is to say, which they could not refer to a general law, as arising from a direct interference of supreme power; and thus for many ages, and among some nations still, eclipses, and earthquakes, and many diseases, particularly those of the mind, and the winds and weather, were or are accounted miraculous. Hence arose among heathens many ceremonies, and sometimes even barbarous sacrifices, for propitiating or appeasing their offended deities; but founded on expectations no more reasonable than if we should now pray to have the day or the year made shorter, or to have a coming eclipse averted. They had not yet risen to the sublime conception of the one God, who said, "Let there be light," and the light was; and who gave to the whole of nature permanent laws, which he allows men to discover for the direction of their conduct in life—laws so unchanging, that by them we can calculate eclipses backward or forward for thousands of years, almost without erring, by the time of one beat of a pendulum; and as our knowledge of nature advances, we can anticipate and explain other events with equal precision. Even the wind and the rain, which in common speech are the types of uncertainty and change, obey laws as fixed as those of the sun and moon; and already, as regards many parts of the earth, man can foretel them without fear of being deceived. He plans his voyages to suit the coming monsoons, and he prepares against the floods of the rainy seasons.

The general laws of nature, divisible as stated above, into the four classes of, 1st. *Physics*, often called *Natural*

*Philosophy* ; 2d. of *Chemistry* ; 3d. of *Life*, commonly called *Physiology* ; and 4th. of *Mind*, may be said to form the pyramid of Science, of which *Physics* is the base, while the others constitute succeeding layers in the order now mentioned ; the whole having certain mutual relations and dependencies well figured by the parts of a pyramid. We must describe them more particularly, to shew these relations.

*Physics*.—The laws of *Physics* govern every phenomenon of nature in which there is any sensible change of place, being concerned alone in the greater part of these phenomena, and *regulating* the remainder which originate from chemical action, and from the action of life.—The great Physical truths, as comprehended in the present day by man, are reduced to four, and are referred to by the words *atom*, *attraction*, *repulsion*, and *inertia*. It gives an astonishing, but true idea of the nature and importance of methodical *Science*, to be told that a man, who understands these words, *viz.* how the ATOMS of matter by mutual ATTRACTION approach and cling together to form masses, which are solid, liquid, or aeriform, according to the quantity or REPULSION of heat among them, and which, owing to their INERTIA or stubbornness, gain and lose motion, in exact proportion to the force of attraction or repulsion acting on them,—understands the greater part of the phenomena of nature ; but such is the fact ! *Solid* bodies existing in conformity with these truths, exhibit all the phenomena of *Mechanics* ; *Liquids* exhibit those of *Hydrostatics* and *Hydraulics* ; *Airs*, those of *Pneumatics* ; and so forth, as seen in the table of heads given below, at page xviii. And the whole of this work is merely a list of the most interesting physical phenomena, arranged in classes under these heads.

*Chemistry*.—Had there been only one kind of substance or matter in the universe, the laws of *Physics* would have explained all the phenomena ; but there are *iron*, and

*sulphur*, and *charcoal*, and about fifty others, which, to the present state of science, appears essentially distinct. Now these, when taken singly, obey the laws of Physics; but when two or more of them are placed in contact under certain circumstances, they exhibit a new order of phenomena. Iron and sulphur, for instance, brought together and heated, disappear as individuals, and unite into a yellow metallic mass, which in most of its properties is unlike to either:—under other new circumstances, the two substances will again separate, and assume their original forms. Such changes are called *chemical* (from an Arabic word signifying *to burn*, because so many of them are effected by means of heat,) but during the changes, the substances are not withdrawn from the influence of the physical laws,—their weight or inertia, for instance, is not altered; and indeed the phenomenon is merely a modification of general *attraction* and *repulsion*. Many chemical changes besides are only the beginnings of purely mechanical changes, as when the new chemical arrangement produced by heat among the intimate atoms of gunpowder, causes the mechanical or physical motion of the sudden expansion or explosion. And all the manipulations of Chemistry, as the transferring of gases from vessel to vessel, the weighing of bodies, pounding, grinding, &c., are directed by Physics alone. Chemistry, then, is truly, as figured above, a superstructure on Physics, and cannot be understood or practised by a person who is ignorant of Physics.—The chief departments of study involving the consideration of Chemical in conjunction with Physical laws, are enumerated in the table below, under the head of CHEMISTRY.

*Life*.—The most complicated state in which matter exists, is where, under the influence of life, it forms bodies with a curious internal structure of tubes and cavities, in which fluids are moving and producing incessant internal change. These are called *Organized Bodies*, because of

the various distinct parts or *organs* which they contain ; and they form two remarkable classes, the individuals of one of which are fixed to the soil, and are called *Vegetables* ; and of the other, are endowed with power of locomotion, and are called *Animals*. The phenomena of growth, decay, death, sensation, self-motion, and many others, belong to life, but from occurring in material structures which subsist in obedience to the laws of physics and chemistry, the life is truly a superstructure on the other two, and cannot be studied independently of them. Indeed the greater part of the phenomena of organic life are merely chemical and physical phenomena modified by an additional principle.—The Science of *Life* is divided into *animal* and *vegetable Physiology* (see the table below).

*Mind*.—The most important part of all science, is the knowledge which man has obtained of the laws governing the operations of his own MIND. This department stands eminently distinct from the others, on several accounts. Unlike that of *organic life*, which could not be understood until physics and chemistry had been previously investigated, this had made extraordinary advances in a very early age, when the others, as methodical sciences, had scarcely begun to exist. In proof of this assertion we need only refer to the writings of the Greek philosophers. The most brilliant discoveries and applications, however, were reserved for the moderns, as will occur to many readers, on perusing in the table below, the several divisions of the subject, and recollecting the honoured names which are now associated with each. It is truly admirable to see the modern analysis, deducing from a few simple laws of mind all the subordinate departments, just as it deduces mechanics, hydrostatics, pneumatics, &c. from the laws of physics : and let us hope that sound opinions on this subject, ensuring human happiness, and therefore beyond comparison more important than any other knowledge, will soon be widely spread.—The crowning science of Mind, although



in certain respects independent of the sciences of Matter, is still closely allied to them in the following ways. The faculties of the mind are originally awakened or called into activity solely by the impressions of matter or external nature ; all the language used in speaking of mind and its operations, is borrowed from matter ; and many mental emotions are entirely dependent on bodily conditions. The science of Mind, therefore, cannot be studied until after knowledge acquired of an external nature ; and cannot be studied extensively until that knowledge be extensive.

*Quantity.*—To express most of the facts and laws of physics, chemistry, and life, terms of QUANTITY are required, as when we speak of the magnitude of a body, or say, that the force of attraction between two bodies diminishes, in a certain proportion, as their distance increases. Hence arises the necessity of having a set of fixed measures or standards, with which to compare all other quantities. Such measures have been adopted ; and they are, for NUMBERS, the fingers, or *fives* and *tens* ; for LENGTH, the *human foot, cubit, pace, &c.* ; and lately the *seconds' pendulum* and the French *mètre* (taken from the magnitude of our globe) ; for SURFACES, the simplest forms of *circle, square, triangle, &c.*, compared among themselves by the lengths of their diameters or other suitable lines ; and for SOLID BULK, the corresponding simple solids, of *globe, cube, pyramid, cone, &c.*, similarly compared by the lengths of diameters or of other lines of dimension. The rules for applying these standards to all possible cases, and for comparing all kinds of quantities with each other, constitute a body of science, called the *Science of Quantity*, or the *Mathematics*. It may be considered as a subsidiary department of human science, created by the mind itself, to facilitate the study of the others.

Supposing *description of particulars, or Natural History*, to be studied along with the different parts of the *System of Science* sketched in the table, there will be

included in the scheme the whole knowledge of the universe which man can acquire by the exercise of his own powers: that is to say, which he can acquire independently of a supernatural *Revelation*. And on this knowledge all his arts are founded,—some of them on the single part of Physics, as that of the machinist, architect, mariner, carpenter, &c. ; some on Chemistry (which includes Physics), as that of the miner, glass-maker, dyer, brewer, &c. ; and some on Physiology (which includes much of Physics and Chemistry), as that of the scientific gardener or botanist, agriculturist, zoologist, &c. The business of teachers of all kinds, and of governors, advocates, linguists, &c. &c., respects chiefly the science of Mind. The art of medicine requires in its professor a comprehensive knowledge of all the departments.

## TABLE OF SCIENCE AND ART.

### 1. PHYSICS.

Mechanics,  
Hydrostatics,  
Hydraulics,  
Pneumatics,  
Acoustics,  
Heat,  
Optics,  
Electricity,  
Astronomy,  
&c.

### 2. CHEMISTRY.

Simple substances,  
Mineralogy,  
Geology,  
Pharmacy,  
Brewing,  
Dyeing,  
Tanning,  
&c.

### 3. LIFE.

Vegetable Physiology,  
Botany,  
Horticulture,  
Agriculture,  
&c.  
  
Animal Physiology,  
Zoology,  
Anatomy,  
Pathology,  
Medicine,  
&c.

### 4. MIND.

*Intellect.*  
Logic,  
Mathematics,  
&c.  
  
*Motives to Action,*  
Emotions and Passions,  
Morals,  
Government,  
Political Economy,  
Theology,  
Education.

IN the first stages of education, *viz.* during the years of childhood and youth, the learning acquired is necessarily of the most mixed kind, and much of it is determined by what is called accident ; but from the mutual dependence of the different departments of science, as explained in the preceding paragraphs, it follows that, with a view to complete erudition, the order exhibited in “ The Table,” is that in which they should afterwards be studied, so as to prevent repetitions and anticipations, and to diminish as much as possible the labour of acquirement.

Every man may be said to begin his education, or acquisition of knowledge, on the day of his birth. Certain objects, repeatedly presented to the infant, are after a time recognized and distinguished. The number of objects thus known gradually increases, and from the constitution of the mind, they are soon associated in the recollection, according to their resemblances, or obvious relations. Thus sweetmeats, toys, articles of dress, &c. soon form distinct classes in the memory and conceptions. At a later age, but still very early, the child distinguishes readily between a *mineral* mass, a *vegetable*, and an *animal* ; and thus his mind has already noted the three great classes of natural bodies, and has acquired a certain degree of acquaintance with *Natural History*. He also soon understands the phrases “ a falling body,” “ the force of a moving body,” and has therefore a perception of the great physical laws of gravity and inertia. Then having seen sugar dissolved in water, and wax melted round the wick of a burning candle, he has learned some phenomena of Chemistry. And having observed the conduct of the domestic animals, and of the persons about him, he has begun his acquaintance with Physiology and the Science of Mind. Lastly, when he has learned to count his fingers and his sugar-plums, and to judge of the fairness of the division of a cake between himself and his brothers, he has advanced into Arithmetic and Geometry. Thus, within a year or two, a child of common

sense has made a degree of progress in all the great departments of human science ; and in addition has learned to name objects, and to express feelings, by the arbitrary sounds of language. Such, then, are the beginnings or foundations of knowledge, on which future years of experience, or methodical education, must rear the superstructure of the more considerable attainments which befit the various conditions of men in a civilized community.

In the course of the preceding disquisition, we have seen that *Physics* or *Natural Philosophy*, the subject of the present volume, is fundamental to the other parts, and is therefore that of which a knowledge is indispensable. Bacon truly calls it "the root of the sciences and arts." That its importance has not been marked by the place which it has held in common systems of education, is owing chiefly, 1st. to the misconception that a knowledge of technical mathematics was a necessary preliminary ; and 2d. to an opinion, also erroneous, that the degree of acquaintance with Physics which all persons acquire by common experience, is sufficient for common purposes : now it is true, that the toys of childhood, as the windmill, ball, syphon, tube, and a hundred others, furnish so many exemplifications of the laws of Physics, and may well be called a philosophical apparatus ; but they give information which is exceedingly vague, and not at all such as is absolutely requisite in the practice of many of the arts. If then, the study of Physics be so easy as now appears, and so important as we shall try still farther to shew, there can be no excuse for neglecting it.

The greatest sum of knowledge acquired with the least trouble, is perhaps that which comes with the study of the few simple truths of Physics. To the man who understands these, very many phenomena, which to the uninformed appear prodigies, are only beautiful illustrations of his fundamental knowledge, and this he carries about with



him, not as an oppressive weight, but as a charm supporting the weight of other knowledge, and enabling him to add to his valuable store every new fact of importance which may offer itself. With such a principle of arrangement, his information, instead of resembling loose stones or rubbish thrown together in confusion, becomes as a noble edifice, of correct proportions and firm contexture, and is acquiring greater strength and consistency with the experience of every day. It has been a common prejudice, that persons thus instructed in general laws had their attention too much divided, and could know nothing perfectly. But the very reverse is true; for general knowledge renders all particular knowledge more clear and precise. The ignorant man may be said to have charged his hundred books of knowledge, to use a rude simile, with single objects, while the informed man makes each support a long chain, to which thousands of kindred and useful things are attached. The laws of Philosophy may be compared to keys which give admission to the most delightful gardens that fancy can picture; or to a magic power, which unveils the face of the universe, and discloses endless charms of which ignorance never dreams. The informed man, in the world, may be said to be always surrounded by what is known and friendly to him, while the ignorant man is as one in a land of strangers and enemies. A man reading a thousand volumes of ordinary books as agreeable pastime, will receive only vague impressions; but he who studies the methodised *Book of Nature*, converts the great universe into a simple and sublime history, which tells of God, and may worthily occupy his attention to the end of his days.

We have said already, that the laws of Physics govern the great *natural* phenomena of Astronomy, the tides, winds, currents, &c. We will now mention some of the *artificial* purposes to which man's ingenuity has made the same laws subservient.

Nearly all that the civil engineer accomplishes ranges

under the head of Physics. Let us take, for instance, the admirable specimens scattered over the British Isles:—the numerous canals for inland traffic; the docks to receive the riches of the world, pouring towards us from every quarter; the many harbours offering safe retreat to the storm-driven mariner; the magnificent bridges which every where facilitate intercourse; hills bored through to open ways for commerce by canals, common roads, and railroads, the canals in some places being supported, like the roads, on arches across vallies or above rivers, so that here and there the singular phenomenon is seen of one vessel sailing directly over another; vast tracts of swamp or fen-land drained, and now serving for agriculture; the noble lighthouse, rearing its head amidst the storm, while the dweller within trims his lamp in safety, and guides his endangered fellow-creature through the perils of the night, &c. &c.

In Holland, great part of the country has been won and is now preserved from the sea, by the same almost creating power; and now rich cities and an extended garden smile, where, as related by Cæsar, were formerly only bogs and a dreary waste.

As a general picture it is interesting to consider, that in many situations on earth where formerly the rude savage beheld the cataract falling among the rocks, and the wind bending the trees of the forest, and sweeping the clouds along the mountain's brow, or whitening the face of the ocean, and regarded these phenomena with awe or terror, as marking the agency of some great but hidden power, which might destroy him; in the same situations now, his informed son, who works with the laws of nature, can lead the waters of the cataract, by sloping channels, to convenient spots, where they are made to turn his mill-wheel, and to do his multifarious work; the rushing winds, also, he makes his servants, by rearing in their course the broad-vented wind-mill, which then performs a thousand offices for its master, man; and the breezes which whiten ocean

are caught in his expanded sails, and are made to waft their lord and his treasures across the deep, for his pleasure or his profit.

In Architecture, also, Physics is supreme, and has directed the construction of the temples, pyramids, domes, and palaces, which adorn the earth.

In respect to machinery generally, Physics is the guiding light. There are, for instance, the mighty steam-engine; machines for spinning and weaving, and for moulding other bodies into various shapes, yea, even iron itself, as if it were plastic clay; windmills, and watermills, and wheel carriages; the plough, and implements of husbandry; artillery and the furniture of war; the balloon, in which man rides triumphantly above the clouds, and the diving-bell, in which he penetrates the secret caverns of the deep; the implements of the intellectual arts, of printing, drawing, painting, sculpture, &c.; musical instruments; optical and mathematical instruments, and a thousand others.

But Physics is also an important foundation of the healing art. The medical man, indeed, is the engineer pre-eminently; for it is in the animal body that true perfection and the greatest variety of mechanism are found. Where, to illustrate *Mechanics*, is to be found a system of levers and hinges, and moving parts, like the limbs of an animal body; where such an *hydraulic* apparatus, as in the heart and blood-vessels; such a *pneumatic* apparatus, as in the breathing chest; such *acoustic* instruments, as in the ear and larynx; such an *optical* instrument, as in the eye; in a word, such variety and perfection, as in the whole of the visible anatomy? All these structures, then, the medical man should understand, as a watchmaker knows the parts of a time-piece about which he is employed. The watchmaker, unless he can discover where a pin is loose, or a wheel injured, or a particle of dust adhering, or oil wanting, &c., would ill succeed in repairing an injury; and so also of the ignorant medical man in respect

to the human body. Yet will it be believed, that there are many medical men who neither understand mechanics, nor hydraulics, nor pneumatics, nor optics, nor acoustics, beyond the merest routine; and that systems of medical education are put forth at this day which do not even mention the department of *Physics*! That such is the case, furnishes an illustration of what is stated in the beginning of this essay; *viz.* that the sciences and arts are progressive, and that perfect methods of education must arise gradually, like all other things of human contrivance. It is within the recollection of persons now living, that political economy was discovered to be a grand foundation of the art of government, indicating means of security against many national misfortunes common in former times, yea, even against famine and war. And the day is not distant, when the members of the medical profession generally will understand how much the correct knowledge of animal structure and function, and of many remedies, must depend on precise acquaintance with *Physics*.— Besides the more strictly professional matters contained in the medical sections of the present work, there are many others scattered through it which greatly interest the medical man; such are the subjects of *meteorology, climate, ventilation* and *warming* of dwellings, *specific gravities*, &c. &c.

The laws of *Physics* having an influence so extensive as appears from these paragraphs, it need not excite surprise that all classes of society are at last discovering the deep interest they have to understand them. The *lawyer* finds that in many of the causes tried in his courts, an appeal must be made to *Physics*,—as in cases of disputed inventions; accidents in navigation, or among carriages, steam engines, and machines generally; questions arising out of the agency of winds, rains, water-currents, &c.: the *statesman* is constantly listening to discussions respecting bridges, roads, canals, docks, and the mechanical industry of the nation: the *clergyman* finds ranged among the



beauties of nature, the most intelligible and striking proofs of God's wisdom and goodness : the *sailor* in his ship has to deal with one of the most admirable machines in existence : *soldiers*, in using their projectiles, in marching where rivers are to be crossed, woods to be cut down, roads to be made, towns to be besieged, &c., are dependent chiefly on their knowledge of Physics : the *land-owner*, in making improvements on his estates, building, draining, irrigating, road-making, &c. : the *farmer* equally in these particulars, and in all the machinery of agriculture : the *manufacturer*, of course : the *merchant* who selects and distributes over the world the products of manufacturing industry—all these are interested in Physics ; then also the *man of letters*, that he may not, in drawing his illustrations from the material world, repeat the scientific heresies and absurdities which have heretofore prevailed, and which, by shocking the now better informed public, exceedingly lower the estimation in which such specimens of the Belles Lettres are held, and lessen their general utility ; and, lastly, *parents of either sex*, whose conversation and example have such powerful effect on the character of their children, who, when grown up, are to fill all the stations in society ; all should study Physics, as one important part of their education.

And it is for such reasons that Natural Philosophy is becoming daily more and more a part of common education. In our cities now, and even in an ordinary dwelling-house, men are surrounded by prodigies of mechanic art, and cannot submit to use these, regardless of how they are produced, as a horse is regardless of how the corn falls into his manger. A general diffusion of knowledge, owing greatly to the increased commercial intercourse of nations, and therefore to the improvements in the Physical departments of astronomy, navigation, &c. is changing every where the condition of man, and elevating the human character in all ranks of society. In remote times, the inhabitants of

the earth were generally divided into small states or societies, which had few relations of amity among themselves, and whose thoughts and interests were confined very much within their own little territories and rude habits. In succeeding ages, men found themselves belonging to larger communities, as when the English heptarchy was united; but still distant kingdoms and quarters of the world were of no interest to them, and were often totally unknown. Now, however, every one feels that he is a member of one vast civilized society, which covers the face of the earth; and no part of the earth is indifferent to him. In England, for instance, a man of small fortune may cast his looks around him, and say with truth and exultation, "I am lodged in a house that affords me conveniences and comforts which, some centuries ago, even a king could not command. Ships are crossing the seas in every direction, to bring me what is useful to me from all parts of the earth. In China, men are gathering the tea-leaf for me; in America, they are planting cotton for me; in the West-Indies, they are preparing my sugar and my coffee; in Italy, they are feeding silk-worms for me; in Saxony, they are shearing the sheep to make me clothing; at home, powerful steam-engines are spinning and weaving for me, and making cutlery for me, and pumping the mines, that minerals useful to me may be procured. Although my patrimony was small, I have post-coaches running day and night, on all the roads, to carry my correspondence; I have roads, and canals, and bridges, to bear the coal for my winter fire; nay I have protecting fleets and armies around my happy country, to secure my enjoyments and repose. Then I have editors and printers, who daily send me an account of what is going on throughout the world, among all these people who serve me. And in a corner of my house I have Books! the miracle of all my possessions, more wonderful than the wishing-cap of the Arabian Tales; for they transport me instantly, not only to all places, but to all times. By my

books I can conjure up before me, into vivid existence, all the great and good men of antiquity ; and for my individual satisfaction I can make them act over again the most renowned of their exploits ; the orators declaim for me ; the historians recite ; the poets sing ; and from the equator to the pole, or from the beginning of time until now, by my books, I can be where I please." This picture is not overcharged, and might be much extended, such being God's goodness and providence, that each individual of the civilized millions dwelling on the earth, may have nearly the same enjoyments as if he were the single lord of all.

Reverting to the importance of Natural Philosophy as a general study, it may be remarked, that there is no occupation which so much strengthens and quickens the judgment. This praise has usually been bestowed on the Mathematics, although a knowledge of abstract Mathematics existed with all the absurdities of the dark ages ; but a familiarity with Natural Philosophy, which comprehends Mathematics, and gives tangible and pleasing illustrations of the abstract truths, seems incompatible with the admission of any gross absurdity. A man whose mental faculties have been sharpened by acquaintance with these exact sciences in their combination, and who has been engaged, therefore, in contemplating *real relations*, is more likely to discover truth in other questions, and can better defend himself against sophistry of every kind. We cannot have clearer evidence of this than in the history of the sciences, since the Baconian method of *reasoning by induction* took place of the visionary *hypotheses* of preceding times. Until then, even powerful minds did not recoil from the most absurd theories on all subjects. Astronomy was mixed with Astrology ; Chemistry with Alchemy ; Physiology with the singular hypotheses which preceded the discovery of the circulation of the blood ; Politics with the errors of monopolies, prohibitions, balance of trade, &c. Even Religion itself, in various ages and countries, has felt

the influence of the state of the public mind as to solid attainments. To a man with the knowledge of nature which we now possess, the fables and licentious abominations of the Greek or Roman theologies are shocking indeed ; as are the religions of the God of Fire in China, or Vishnoo in India, of Mahomet's imposture and pretended miracles, &c. But the enlightened Christian minister earnestly recommends the study of nature ; first, because from contemplating the beauty of creation, with the wisdom and benevolent design manifest in all its parts, there spring up in every undepraved mind those feelings of admiration and gratitude, which constitute the adoration of natural religion, and which form, as shewn by many estimable writers on Natural Theology, a fit foundation for the sublime doctrine of immortality ; and secondly, because a Revelation being provable only by the miracles occurring at its establishment ; to enable men to distinguish between miracles and the usual course of nature, a perfect knowledge of that course, or of Natural Philosophy, is essential : all the false religions of antiquity were founded on, and upheld by pretended miracles. As regards the question of immortality, even independently of Revelation, no man who contemplates the order and beauty of the material world, and then thinks on the hideous deformities of the moral world—where vice so often triumphs, and modest virtue pines and dies—can for a moment believe that they are the work of the same author, unless there be an hereafter of retribution ; and feeling thus that eternal justice requires another state for man, he embraces with delight the cheering promises of immortality. There have been, however, at various times, even among Christians, sincere, but weak-minded or ill-informed men, who decried the study of the natural sciences, as inimical to true religion ; as if God's ever-visible and magnificent revelation of his attributes in the structure of the universe could be at variance with any other revelation. But such prejudices are now quickly passing away. Where-



ever considerable knowledge of nature exists, debasing and gloomy superstition must cease. It is not the abject terror of a slave which is inspired by contemplating the majesty and power of our God, displayed in his works, but a sentiment akin to the tender regard which leads a favoured child to approach with confidence a wise and indulgent parent.

It remains for the author now only to say a few words with respect to the present work. He was originally led to the undertaking with the view of supplying the desideratum in medical literature, of a treatise on *Medical Physics*; but soon perceiving that the preliminary investigation of *General Physics*, necessary to adapt the work to medical readers, would require to be nearly as extensive as if it were for general readers, and reflecting that every person of liberal education must now possess such a book, not to be read once and then thrown aside as a novel is, but to be frequently consulted as a manual, he determined to make his book as complete and as extensively useful as possible. He has been encouraged, during his labour, by the belief, that the growing light of science, which now exhibits more clearly the natural relations of the different departments of study, as attempted to be portrayed in the preceding pages, might enable him to avoid some of the defects of former elementary treatises, and to add features of novelty and improvement to his own. The sections on *Animal Physics* were, of course, written for medical men; and a great service will be rendered by the work, if it only awakens them to a just sense of the importance of Physics as one of the foundations of their art. But even for general readers there are few parts of these sections which the author would exclude. There is nothing more admirable in nature than the structure and functions of the human body, and there are many reasons why no liberal mind should be careless of the study. The details here given are not more anatomical than the illustrations

from the animal economy contained in the common treatises on *Natural Theology*. From the attempt in this work, to compress into the smallest possible space the greatest possible sum of scientific information, few historical details have been admitted, whether relating to the distinguished men who have benefitted the world as authors or inventors, or to the history of the progress of science:—such details form an interesting, but distinct branch of study.

The author must not conclude without observing, that no treatise on Natural Philosophy can save, to a person desiring full information on the subject, the necessity of attendance on experimental lectures or demonstrations. Things that are seen, and felt, and heard, that is, which operate on the external senses, leave on the memory much stronger and more correct impressions than where the conceptions are produced merely by verbal description, however vivid. And no man has ever been remarkable for his knowledge of Physics, Chemistry, or Physiology, who has not had *practical familiarity* with the objects. With reference to this familiarity, persons who take a philanthropic interest in the affairs of the world, must observe with much pleasure, the now daily increasing facilities of acquiring useful knowledge, afforded by the scientific institutions formed and forming, not only through this kingdom, but through most civilized nations.

*Bedford Square,*  
*1st March 1827.*

# ELEMENTS

OF

## NATURAL PHILOSOPHY.

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### SYNOPSIS, OR GENERAL VIEW.

IF it excite our admiration that a varied edifice, or even a magnificent city, can be constructed of stone from one quarry, what must our feeling be to learn how few and simple the elements are, out of which the sublime fabric of the universe, with all its orders of phenomena, has arisen, and is now sustained! These elements are general facts and laws which human sagacity is able to detect, and then to apply to endless purposes of human advantage.

Now the four words, *atom*, *attraction*, *repulsion*, *inertia*, point to four general truths, which explain the greater part of the phenomena of nature. Being so general they are called *physical* truths, from the Greek word signifying *nature*, as also “truths of Natural Philosophy,” with the same meaning, and sometimes “mechanical truths,” from their close relation to ordinary machinery. These appellations distinguish them from the remaining general truths, namely, the *chemical* truths, which regard particular substances, and the *vital* and mental truths, which have relation only to

living beings. And even in the cases where a chemical or vital influence operates, it modifies, but does not destroy, the physical influence. By fixing the attention then on these *four fundamental truths*, the student obtains, as it were, so many keys to unlock, and lights to illumine the secrets and treasures of nature.

1st. **ATOM.** Every material mass in nature is divisible into very minute indestructible and unchangeable particles,—as when a piece of any metal is bruised, broken, cut, dissolved, or otherwise transformed, a thousand times, but can always be exhibited again as perfect as at first. This truth is conveniently recalled by giving to the particles the name *atom*, which is a Greek term, signifying *that which cannot be farther cut or divided*, or an exceeding minute resisting particle.

2d. **ATTRACTION.** It is found that the atoms above referred to, whether separate or already joined into masses, tend towards all other atoms or masses,—as when the atoms of which any mass is composed are, by an invisible influence, held together with a certain degree of force; or when a block of stone is similarly held down to the earth on which it lies; or when the tides on the earth rise towards the moon. These facts are conveniently recalled by connecting with them the word *Attraction* (a drawing together), or *gravitation*.

3d. **REPULSION.** Atoms under certain circumstances, as of heat diffused among them, have their mutual *attraction* countervailed or resisted, and they tend to separate;—as when ice heated

melts into water, or when water heated bursts into steam, or when gunpowder ignited explodes. Such facts are conveniently recalled by the term *Repulsion* (a thrusting asunder).

4th. *INERTIA*. As a fly-wheel made to revolve, at first offers resistance to the force moving it, but gradually acquires speed proportioned to that force, and then resists being again stopped, in proportion to its speed, so all bodies or atoms in the universe have about them, in regard to motion, what may be figuratively called a *stubbornness*, tending to keep them in their existing state, whatever it may be—in other words, they neither acquire motion, nor lose motion, nor bend their course in motion, but in exact proportion to some force applied. Many of the motions now going on in the universe with such regularity—as that turning of the earth which produces the phenomena of day and night—are motions which began thousands of years ago, and continue unvarying in this way. Such facts are conveniently recalled by the term *inertia* applied to them.

A person comprehending fully the import of these four words, that is to say, having present to his mind numerous good types or exemplars of the facts referred to by them, may predict or anticipate correctly, and may control, very many of the facts and phenomena, which the extended experience of a life can display to him; and such a person is commonly said to know the causes or reasons of things and events. Now it is important here to observe, that when a person gives a reason or explanation of any fact, other than



that it is a fact, or than that the Creator has willed it, he is merely, although he may not be aware of this, shewing its resemblance to many other facts, no one of which he understands better than itself—and what he calls a general truth, or law, or principle, is merely an expression for the observed but unaccountable resemblance of the facts. Thus, when a man says that a stone falls because of *attraction* or *gravitation*, he only uses a word which recalls thousands of instances which he has witnessed of one body approaching another; but any cause of the approach, other than that God has willed it, is to him utterly unknown. Should men in the progress of their researches, discover that the phenomena now classed by them under the heads of *attraction* and *repulsion*, although apparently opposite, are really as closely allied as they already know the rising of a balloon and the falling of a stone to be (the balloon rises like a cork in water, being pushed up by the fluid air around it, heavier than it, and seeking to descend), they will not have discovered a new cause, but a new resemblance, (new to them) among phenomena, and will only have advanced one step further in perceiving the simplicity of creation. In accordance with these views, it will be found that this volume is chiefly an extensive display of the most important phenomena of nature and art, classified so as to be explained by the four physical truths, and mutually to illustrate one-another. They will be distributed under the following heads or divisions:

## PART I.

## THE FOUR FUNDAMENTAL TRUTHS.

These great truths extensively examined, and used to explain generally, in

## Section

1. The *nature or constitution of the material masses* which compose the universe; (a department technically called SOMATOLOGY, from Greek words signifying a *discourse* on *body*).
2. The *motions or phenomena* going on among the masses;—a department including the common divisions of STATICS (things stationary or at rest), and DYNAMICS (what relates to *force* or *power*).

## PART II.

## PHENOMENA OF SOLIDS.

The four truths explaining the peculiarities of state and motion among *solid* bodies:—a department called, in a restricted sense, MECHANICS, (from the Greek word signifying a *machine*).

## PART III.

## PHENOMENA OF FLUIDS.

The truths explaining the peculiarities of state and motion among *fluid* bodies:—a department called HYDRODYNAMICS (from Greek words signifying *water* and *force*).

## Section

1. HYDROSTATICS (*water at rest or in equilibrium*).
2. PNEUMATICS (*air phenomena*).
3. HYDRAULICS (*water or fluid in motion*).
4. ACOUSTICS (*phenomena of sound and hearing*).

## PART IV.

## PHENOMENA OF IMPONDERABLE SUBSTANCE.

The truths aiding to explain the more recondite phenomena of IMPONDERABLE SUBSTANCE, under the heads of

Section

1. HEAT or *Caloric*.
2. LIGHT or *Optics*.
3. ELECTRICITY (from the Greek word signifying *amber* ; the electric light having been first obtained from amber):
4. MAGNETISM.

## PART V.

## PHENOMENA OF THE HEAVENS.

A department commonly called ASTRONOMY (from Greek words signifying *laws* of the *stars*).

Under each head, in addition to the phenomena of general nature, will be ranged the most interesting illustrations afforded by the animal economy, constituting—ANIMAL AND MEDICAL PHYSICS.

As no man can well understand a subject of which he does not carry a distinct outline in his mind, it is recommended to the reader of this work to study the general *synopsis*, and the *analyses* placed at the heads of the *chapters* and *sections*, until the memory be well impressed with them.



## PART I.

THE FOUR FUNDAMENTAL TRUTHS MINUTELY EXAMINED,  
AND USED TO EXPLAIN GENERALLY, FIRST, THE NATURE  
OR CONSTITUTION OF THE MATERIAL MASSES WHICH  
COMPOSE THE UNIVERSE, AND SECONDLY, THE MOTIONS  
OR PHENOMENA GOING ON AMONG THEM.

## SECTION I.—THE CONSTITUTION OF MASSES.

## ANALYSIS OF THE SECTION.

*The visible universe is built up of very minute indestructible ATOMS called matter, which, by mutual ATTRACTION, cohere or cling together in masses of various form and magnitude. The atoms are more or less approximated, according to the quantity or REPULSION of heat among them, and hence arise the three remarkable forms in the masses, of solid, liquid, and air, which mutually change into each other with change in the quantity of heat. Certain modifications of attraction and repulsion produce the subordinate peculiarities of state called crystal, dense, hard, elastic, brittle, malleable, ductile, and tenacious.*

“ *Minute Indestructible ATOMS.*”\*

THAT the smallest portion of any substance which  
the human eye can perceive, is still a mass of

\* The different heads or titles, which appear thus, throughout the work, between inverted commas, are the successive portions of the *Analyses*, detached for separate consideration. The reader is particularly requested to reperuse the analysis at the several interruptions, that he may have constantly before him that clear view of the general relations among the different parts of the subject, which is essential to a perfect understanding of it.

(1.)

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many ultimate atoms or particles, which may be separated from each other, or newly arranged, but which cannot individually be hurt or destroyed, is deduced from such facts as the following :

A particle of powdered marble, hardly visible to the naked eye, still appears to the microscope a block susceptible of indefinite division ; and, when it is broken by fit instruments, until the microscope can hardly discover the separate particles of the fine powder, these may be yet farther divided, by solution in an acid ; the whole becoming then absolutely invisible, as part of a transparent liquid.

A small mass of gold may be hammered into thin leaf, or drawn into fine wire, or cut into almost invisible parts, or liquefied in a crucible, or dissolved in acid, or dissipated by intense heat into vapour ; yet, after any and all of these changes, the atoms can be collected again to form the original mass of gold, without the slightest diminution or change. And all the substances or elements of which our globe is composed, may thus be cut, torn, bruised, ground, &c. a thousand and a thousand times, but are always recoverable as perfect as at first.

And, with respect to delicate combinations of these elements, such as exist in animal and vegetable bodies, although it be beyond human art, originally to produce, or even closely to imitate many of them—for we cannot build up a feather or a rose, still, in their decomposition and apparent destruction, the accomplished chemist of the present day does not lose a single atom. The

coal which burns in his apparatus, until only a little ash remains behind, or the wax-taper which seems to vanish altogether in flame, or the portion of animal flesh, which putrifies, and gradually dries up and disappears—present to us phenomena which are now proved to be only changes of connexion and arrangement among the indestructible ultimate atoms ; and the chemist can offer all the elements again, mixed or separate, as desired, for any of the useful purposes to which they are severally applicable. When the funeral piles of the ancients, with their charge of human remains, appeared to be wholly consumed, and left the idea with survivors that no base use could be made, in after time, of what had been the material dwelling of a noble or beloved spirit, the flames had only, as it were, scattered the enduring blocks of which a former edifice had been constructed, but which were soon to serve again in new combinations.

Facts, to be stated under the heads of “ chemical composition” and “ crystal,” will prove, that the ultimate particles of any substance must be, among themselves, perfectly similar.

“ *Minute.*” (Read the Analysis, page 7.)

The following are interesting particulars in the arts or in nature, helping the mind to conceive how minute the ultimate atoms of matter must be.

Goldbeaters, by hammering, reduce gold to leaves so thin, that 360,000 must be laid upon one another to produce the thickness of an inch.

They are so thin, that if formed into a book, 1,800 would occupy only the space of a single leaf of common paper: and an octavo volume an inch thick would have as many pages as the books of a well-stocked ordinary library containing 1,800 volumes of 400 pages in each; yet those leaves are perfect, or free from holes, so that one of them laid upon any surface, as in gilding, gives the appearance of solid gold.

Still thinner than this is the coating of gold, upon the silver wire of what is called gold lace; and we know not that such coating is of only one atom thick. If we place a piece of this wire in nitric acid, so as to dissolve the silver from within, the gold coating remains as a metallic tube of exquisite tenuity.

Platinum can be drawn into wire much finer than human hair.

A grain of blue vitriol, or carmine, will tinge a gallon of water, so that in every drop the colour may be perceived.

A grain of musk will scent a room for twenty years, and will have lost but little of its weight.

The carrion crow seems to smell its food at a distance of many miles.

The thread of the silk-worm is so small, that many folds have to be twisted together to form our finest sewing thread; but that of the spider is smaller still, for two drachms of it by weight would reach from London to Edinburgh, or 400 miles.

In the milt of a cod-fish, or in water in which certain vegetables have been infused, the microscope discovers animalcules, of which many thou-

sands together do not equal in bulk a grain of sand; yet, these have their blood and other subordinate parts like larger animals; and indeed nature, with a singular prodigality, has supplied many of them with organs as complex as those of the whale or elephant. Now the body of an animalcule consists of the same elementary substances, or ultimate atoms, as the body of man himself. In a single pound of matter, it thus appears, that there may be more living creatures than of human beings on the face of this globe. What scenes has the microscope laid open to the admiration of the philosophic inquirer!

Water, mercury, sulphur, or, in general, any substance, when sufficiently heated, rises as invisible vapour or gas; in other words, is made to assume the aeriform state. Great heat, therefore, would cause the whole of the material universe to disappear, the previously most solid bodies becoming as invisible and impalpable as the air we breathe. Utter annihilation would seem but one stage beyond this.

“ *Matter.* ”

The inconceivable minuteness of ultimate atoms, as shewn above, has led some inquirers to doubt whether there really be *matter*; that is to say, whether what we call substance or matter, have existence or not. In answer to this, it has been usual to adduce, besides the weight of the substances, and the proofs of indestructibility already mentioned, which seem conclusive, the fact, that every kind or portion of matter obstinately occupies



some space, to the exclusion of all other matter from that particular space. This occupancy of space is the simplest and most complete idea which we have of material existence. The awkward word *impenetrability* has been used to express it, with reference of course to the individual atoms. The following are elucidations.

We cannot push one billiard-ball into the substance of another, and then a second, and then a third, and so on; or the material of the universe might be absorbed in a point.

A mass of iron on a support will resist the weight of thousands of pounds laid upon it and pressing to descend into its place; and although a very great weight might crush or break it into pieces, still one particle would not be annihilated. In a forcing-pump, or in Bramah's water-press, millions of pounds cannot push the piston down, unless the water below it be allowed to escape.

A weight laid upon bladders full of air, or on the piston-handle of a closed air-pump, is supported in the same manner.

A quantity of air escaping from a vessel under water ascends through the water as a bubble, displacing its bulk of water in its way.

A glass tube, left open at bottom, while the thumb closes the top, if pressed from air into water, is not filled with water, because the air contained in it resists; but if the air be allowed to escape by removing the thumb from the top, the tube becomes filled immediately to the level of the water around it. In a goblet or basin pushed into water, with the mouth downwards, the entrance



of water is resisted for the like reason ; and if the goblet be inverted over a floating lighted taper, this will continue to float under it, and to burn in the contained air, however deep in the water it be carried—exhibiting the curious phenomenon of a light below water, and being an emblem of the living inmate of a diving bell, which is merely a larger goblet holding a man instead of a candle.

“*Mutual ATTRACTION.*” (See the Analysis, page 7.)

Any visible mass of matter, then, as of metal, salt, sulphur, &c., we know to be really a collection of dust, or minute atoms, by some cause made to cohere or cling together ; yet there are no hooks connecting them, nor nails, nor glue ; and the connexion may be broken a thousand times, by processes of nature or art, but is always ready to take place again ; the cause being no more destroyed in any case by interruption, than the weight of a thing is destroyed by frequent lifting from the ground. Now the cause we know not, but we call it *attraction*. The phenomena of attraction and its contrary, repulsion, particularly when occurring between bodies at considerable distances from each other, are as inexplicable as any subjects which the human mind has to contemplate ; but the manner or laws of the phenomena are now well understood. The general nature and extensive influence of attraction may be judged of from the following facts.

Logs of wood floating in a pond, or ships in calm water, approach each other, and afterwards remain in contact. When the floating bodies are very small, or can approach very near to each other

at the water's edge—as glass bulbs in a teacup—an additional force is called into play, as will be explained under the head of “capillary attraction.”

The wreck of a ship, in a smooth sea after a storm, is often seen gathered into heaps.

Two bullets or plummets suspended by strings near to each other, are found by the delicate test of the torsion balance (which will be described afterwards) to attract each other, and therefore not to hang quite perpendicularly.

A plummet suspended near the side of a mountain inclines towards it, in a degree proportioned to its magnitude; as was ascertained by the well-known trials of Dr. Maskeleyne near the mountain Schehallion, in Scotland.

And the reason why the plummet in such a case tends much more strongly towards the earth than towards the hill, is only that the earth is larger than the hill.

At New South Wales, which is situated on our globe nearly opposite to England, plummets hang and fall towards the centre of the globe, as they do here; so that, in respect to England, they are hanging and falling upwards, and the people there, like flies on the opposite side of a pane of glass, are standing with their feet towards us,—hence called our antipodes. Weight, therefore, is merely general attraction acting every where.

But it is owing to this general attraction that our earth itself is a globe:—all its parts being drawn towards each other, that is, toward a common centre, the mass assumes the spherical or rounded form.

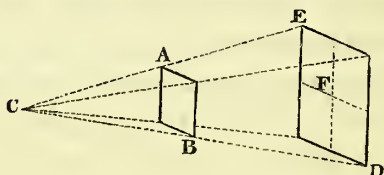
And the moon also is round, and all the planets; nay the glorious sun too, so much larger than these, is round;—suggesting the inference that all must at one time have been to a certain degree fluid, and that all are subject to the same law.

Descending again to the earth and observing minuter masses, we have many interesting instances of roundness from the same cause; as—the particles of a mist or fog floating in air—these, mutually attracting and coalescing into larger drops, and so forming rain—dew-drops—water trickling on a duck's wing—the tear dropping from the cheek—drops of laudanum—globules of mercury, like pure silver beads, coalescing when near, and forming larger ones—melted lead allowed to rain down from an elevated sieve, and by cooling as it descends so as to retain the form of its liquid drops, becoming the spherical shot-lead of the sportsman, &c.

The cause of the extraordinary phenomenon which we call attraction, acts at all distances.—The moon, though 240,000 miles from the earth, by her attraction, raises the water of our ocean under her, and forms what we call the tide.—The sun, still farther off, has a similar influence; and when the sun and moon act in the same direction, we have the spring tides.—The planets, so distant that they appear to us little wandering points in the heaven, yet, by their attraction, affect the motion of our earth in her orbit, quickening it when she is approaching them, retarding it when she is receding.

The *attraction is greater* the nearer the bodies are to each other; as the light of a taper is more intense near to the taper than at a distance.

A board of a foot square, represented in this figure by AB, at a certain distance from a light, supposed at C, just shadows a board of two feet square, as ED, at double distance; but a board with a side of two feet has four times as much surface as a board with a side of one foot, for it is not only twice as high or long, which would make it double, but twice as broad also, which makes it



quadruple—as a globe of two feet diameter requires just four times as much paper to cover it as a globe of one foot,—and the corner, or fourth part, EF, of the larger square here shewn is just equal to the whole of the smaller square AB. Light, therefore, at double distance from its source, being spread over four times the space, has only one-fourth of the intensity; and for a similar reason, at thrice the distance it has only a ninth part, at four times a sixteenth part, and so on. Now light, heat, attraction, sound, and indeed every influence from a central point, is found to decrease in the proportion here illustrated, *viz.* as the surface of squares which shadow one another increases. The technical expression is, “*the intensity is inversely as the square of the dis-*



*tance* ;” (the distances being estimated from the centres of attraction or radiation) or one-fourth part as strong at double distance, four times as strong at half distance, and in a corresponding manner for all other distances.

Accordingly, what weighs 1,000 lbs. at the sea-shore, weighs five lbs. less at the top of a mountain of a certain height, or when raised in a balloon—as is proved experimentally by a spring balance, or other means ;—and at the distance of the moon, the weight, or force towards the earth, of 1000 lbs., is diminished to five ounces, as is proved by astronomical tests.

ATTRACTION has received different names, as it is found acting under different circumstances.

The chief distinctions are *Gravitation*, *Cohesion*, *Capillary* and *Chemical attractions*.

*Gravitation* is the name given to it when acting at sensible distances, as in the cases of the moon lifting the tides—the sun and earth attracting each other—a stone falling, &c. Most of the facts enumerated at page 14, belong to this head.

*Cohesion* is the name given, when it is acting at very short distances, as in keeping the atoms of a mass together.

It might appear at first sight that it cannot be the same cause which draws a piece of iron to the earth with the moderate force called its weight, and which maintains the constituent atoms of the iron in such strong cohesion ; but when we recol-

lect that attraction is stronger as the substances are nearer to each other, the difficulty is met. Atoms very nearly in contact may be a million times nearer to each other, than when only a quarter of an inch apart, and therefore when the heat among the atoms of any mass allows them to approach very near, they should attract mutually with great force.

If, then, the surfaces of bodies were not in general so very rough and irregular, that, when applied to each other, they can touch only in a few points of the million perhaps which each surface contains, bodies would be invariably sticking together or cohering by any accidental contact. The effect of artificially smoothing the touching surfaces is seen in the following examples:—we may remark, however, that besides irregularity of surface, there is another reason, explained a little further on, which prevents the cohesion.

Similar portions being cut off with a clean knife from two leaden bullets, and the fresh surfaces being brought into contact with a slight turning pressure, the bullets cohere, almost as if they had been originally cast in one piece.

Fresh-cut surfaces of India-rubber or caoutchouc cohere in a similar way. We may hence make elastic air-tight tubes, by cutting off the edges of a strip of India-rubber and bringing the cut surfaces into contact by winding the strip spirally round any small rod or cylinder, and fixing it there for a time with tape or cord.

Two pieces of perfectly smooth plate-glass or marble, laid upon each other, adhere with great



force : and indeed so do most well-polished flat surfaces.

Cohesion between a solid and liquid, and between the particles of a liquid among themselves, is seen in the following instances.

A flat piece of glass, balanced at the end of a weighing beam, and then allowed to come into contact with water, adheres to the water, and with much more force than the weight of water remaining upon it when again forcibly raised. If there were not cohesion or attraction of the water particles among themselves, as well as to the glass, the latter could only be held down by the weight of the water which directly adhered to it.

In pouring water from a mug or bottle-lip, the water does not at once fall perpendicularly, but runs down along the inclined outside of the vessel ; chiefly in consequence of the attraction between this and the water ; hence the difficulty of pouring from a vessel which has not a projecting lip.

The particles of water cohere among themselves in a degree which causes small needles gently laid on the surface to float :—the weight of the needles is not sufficient to overcome the cohesion of the water surface.

For the same reason many light insects can walk upon the surface of water without being wetted.

It is chiefly the different force of the attraction of cohesion in different liquids that causes their drops or gutts from the lip of a phial to be of different magnitude. Sixty drops of water fill the

same measure as 100 drops of laudanum from a lip of the same size.

In a larger mass of liquid, the attraction which, if acting alone, would draw the particles into the form of a distinct globe, yields to that which draws them towards the centre of the earth, and therefore the liquid assumes, more or less completely, what is called a level surface, that is to say, a surface corresponding with the general surface of the globe of the earth.

*Attraction* is called *capillary* when it acts between a liquid and the interior of a solid, which is tubular or porous.

When an open glass tube is partially immersed in water, the water within it stands above the level of that on the outside; and the difference of level is greater as the tube is less, because, in small tubes, the glass all round being nearer to the raised water, attracts it more powerfully.

Between two plates of glass standing near to each other, with their lower edges in water, a similar rising of water will occur; and if they are closer at one perpendicular edge than at the other, the surface of the suspended water will be higher there. The two plates of glass in such a case are found to be drawn towards each other by the interposed waters with a certain force, as happens also to glass beads, or other small bodies, floating in water with their surfaces so near to each other at the water's edge, that the water may rise between them,—and the nearer they approach the higher the water rises, and the more strongly it attracts.

Water, ink, or oil, coming in contact with the edge of a book, is rapidly absorbed far inwards among the leaves.

A piece of sponge or a lump of sugar touching water by its lowest corner, soon becomes moistened throughout.

The wick of a lamp lifts the oil to supply the flame, from two to three inches below it.

A mass of cotton thread hanging over the edge of a glass from the water within it will empty it, as a syphon would. A towel will empty a basin of water in the same way.

Dry wedges of wood driven into a groove formed round a pillar of stone, on being moistened, will swell so as to rive off the portion from the block. In some quarries of Germany mill-stones are thus cut from the rock.

An immense weight or mass suspended by a dry rope may be raised a little way, by merely wetting the rope:—the moisture imbibed by capillary attraction into the substance of the rope causes it to swell laterally and to become shorter.

At one time the small vessels of vegetables were supposed to raise the sap from the roots, by capillary attraction; but this is known now to be chiefly an action of vegetable life.

*Attraction* has received the name of *chemical attraction*, or *affinity*, when it unites the atoms of two or more distinct substances into one perfect compound.

There are about fifty substances in nature which appear, in the present state of science, distinct

from each other, and are therefore called *kinds of matter*: such as the various metals, sulphur, phosphorus, &c.; but whether these are, in truth, originally and essentially different, or are all only one simple primordial matter, modified by circumstances as yet unknown to us, we cannot at present positively determine. Diamond and pure black carbon are the same substance only with different arrangement of atoms; and steel, which in the soft state the graver cuts as it would copper or silver, is exactly the same substance as when, after being tempered by heating and sudden cooling, it has become as hard nearly as diamond itself. Yet these differences are more striking than appear between some substances, which we now account essentially distinct.

It is found, however, that the atoms of what we call different substances will not cohere and unite indifferently, to form masses, as atoms of the same kind do,—there being singular preferences and dislikes among them, if it may be so expressed, or affinities as the chemists term it; and when atoms of two kinds do combine, the resulting compound generally loses all resemblance to either of the elements.—Thus:

Sulphuric acid will unite with copper and form a beautiful translucent blue salt; with iron it will form a green salt; and if a piece of iron be thrown into a solution of the copper salt, the acid will immediately let fall the copper, and take up or dissolve the iron.—Sulphuric acid will not unite with or dissolve gold at all.—Quicksilver and sulphur unite in certain proportions and form the



paint called vermilion : in other proportions they form the black mass called Ethiops Mineral.—Lead with oxygen absorbed from the atmosphere or other source forms what is called red lead, used by painters.—Sea-sand, or flint, and the substance called soda, when heated together, unite and form that most useful substance called glass.—Certain proportions of sulphur and of iron combine and produce those beautiful cubes of pyrites, or gold-like metal, which are seen in slate. Chemical attraction operating thus, does not in the slightest degree interfere with general attraction or gravity, for every chemical compound weighs just as much as its elements taken separately.

The history and classification of all such facts connected with the combinations and analysis of different substances, constitute the science of chemistry, so attractive and so useful. It explains how the fifty kinds of matter above alluded to, by variously combining, form the endless diversity of bodies which constitute, as far as it has yet been explored, the mass of our globe. The reasons of these various modifications of attraction are yet much hidden from us.

It is a remarkable truth, that when different substances combine in the way now described, the proportions of the ingredients are always uniform, and such as to lead to the conclusion, that for every atom present, of one substance, there is exactly one, or two, or three, &c. of the other ; so that, if there be ten atoms of one substance, there are exactly ten, or twenty, &c. of the other, but never

an intermediate number, as 13 or 23 to 10, for then a particle of the compound would consist of one atom of the first, and of one and three-tenths, or two and three-tenths, &c. of the second substance, an absurdity if the atom be indivisible. For instance, a certain number of atoms of quicksilver, which weigh twenty-five grains, combine with a certain number of atoms of sulphur, weighing two grains, and form a black compound called Ethiops Mineral, or black sulphuret of mercury; and if a little more of either ingredient be added, it lies as a foreign mixture in the sulphuret of mercury; but if just as much more sulphur be added as at first, so that there may be two atoms of it, instead of one, in every particle of the compound, a perfect combination of the whole will take place, and a new substance will appear which we call vermilion. Many elementary substances will only unite with each other in one proportion, so that any two such substances form only one compound: but others unite in several proportions, so that several distinct compounds arise out of the same two elements.

It thus appears, that although we do not know the exact number of atoms in a given quantity of any substance,—whether, for instance, a grain of sulphuret of mercury has more or less than a million of them; still as we know that in that grain there are just as many atoms of sulphur as of mercury, and that the weight of the whole sulphur to that of the whole mercury is as two to twenty-five, we know that the single atoms must have the same relation, or that the atom



of mercury is  $12\frac{1}{2}$  times as heavy as that of sulphur.

Tables have been formed exhibiting the relative weights of the atoms of different substances; and the number standing opposite to each substance is called its *chemical equivalent*,—that is to say, the weight of its atom in relation to the weight of the atom of some other substance chosen as a standard. The *equivalent* of a compound substance depends of course both on the equivalents of the ingredients, and on the number of atoms existing in one integrant particle of the compound.

There is no such thing as an *atom* of vermilion, or of any other compound, for the ultimate molecule or particle must contain at least one atom of the respective ingredients.

The facts of the peculiarities and constancy of chemical unions are among the strongest arguments for the existence of similar ultimate atoms.

Besides the simple cases of attraction now explained, there are two curious modifications, called *electrical* and *magnetical* attractions, which, from their peculiarities, are reserved for consideration in a future division of this work.

“*Atoms are more or less close, according to the quantity or REPULSION of heat among them; hence the forms of solid, fluid, air, &c.*” (Read the Analysis, p. 7.)

Were there in the universe only atoms and attraction, as hitherto explained, the whole material of creation would rush into close contact,

forming one huge solid mass of stillness and death. But there is also heat or caloric, which counteracts attraction, and singularly modifies the results. It has been described by some as a most subtile fluid, pervading all things, somewhat as water pervades a sponge; others have accounted it merely a vibration among the atoms. The truth is, that we know little more of heat as a cause of repulsion, than of gravity as a cause of attraction: but we can study and classify most accurately the phenomena of both.

When a continued addition of heat is made to any body, it gradually increases the mutual distance of the constituent atoms, or dilates the body. A solid thus is first enlarged and softened; then melted or fused, that is to say, reduced to the state of liquid, as the cohesive attraction is overcome; and lastly, the atoms are repelled to still greater distances, so that the substance is converted into elastic fluid or air. Abstraction of heat from such air causes return of states in the reverse order.

Thus ice when heated becomes water, and the water when farther heated becomes steam: the steam when cooled again becomes water as before, and the water when cooled becomes ice. Ice, water, and steam, therefore, are three forms or states of the same substance—one of the most common in nature, being the material of the ocean.

Other substances are similarly affected by heat, but as all have different relations to it, some requiring much for liquefaction, and some very little,

we have that beautiful variety of solids, liquids, and airs, which constitutes our external nature.

*Dilatation.*—A rod of iron, which, when cold, will pass through a certain opening, and will lie lengthwise between two fixed points, when heated, becomes too thick and too long to do either.—For accurate mensuration, therefore, rods or chains used as the measure, must either be at a given temperature, or due allowance must be made for the difference.

The walls of a building, under the pressure of a heavy roof, had begun to bulge out so as to threaten its stability. No force tried was sufficient to restore them to perpendicularity, until the idea occurred of using the contracting force of cooling iron. The opposite walls were then connected by a number of iron bars, passing through both, and having nuts to screw close to the wall, upon their projecting ends, of which bars one-half were heated at a time, *viz.* every second or alternate bar, by lamps placed under them, and while lengthened in consequence, and projecting farther beyond the wall, their nuts were again screwed close up; so that, on cooling and contracting, they pulled the wall in a degree back to its place. The nuts of the second set of bars being then screwed home, the others were again heated, and advanced the object as much as the first; and so on, until the object was accomplished.

The iron rim of a coach-wheel, when heated, goes on loosely and easily, but when afterwards cooled, it binds the wheel most tightly, giving remarkable firmness and strength.

Iron hoops on masts and on casks are made to bind in a similar manner.

The common thermometer for measuring degrees of heat, is a glass bulb filled with mercury or other fluid, and having a narrow tube rising from it, into which the fluid, on being expanded by heat, ascends, and so marks the degree.

A bladder not quite full of cold air, on being heated becomes tense, and if weak may even be burst.

*Liquid and Air.*—A piece of gold, lead, pitch, ice, sulphur, or of other thing, if sufficiently heated, melts or becomes liquid; each substance, however, requiring a different degree of heat—gold requires 5,000 degrees, lead 600, ice 32, and so forth; and if the heating be afterwards continued, most things at certain higher temperatures suddenly expand again to many times the liquid volume, and become aeriform fluids.

The conversion of water into steam is familiarly known to all. One pint of water driven off as steam from the boiler of a low-pressure steam-engine, fills a space of nearly 2,000 pints, and raises the piston through this, with a force of many thousands of pounds: it immediately afterwards appears again in the cold condenser as a pint of water.

Six times as much heat is required to convert a pint of water into steam, as to raise it from an ordinary temperature to that of boiling; but the steam by occupying nearly 2,000 times the space of the water, proves that heat merely produces a repulsion among the particles, and by no means

fills up the interstices. The steam rising from boiling water, does not appear to the thermometer hotter than the water itself; and hence it was that Dr. Black, whose genius shed so much light on this part of knowledge, gave to the excess of heat the name of *latent heat*.

The latent heat of common air is made sensible in the *match syringe*. In this, which is close at the bottom, the piston is driven down quickly and strongly, so as to compress very much the air which is underneath it, and the heat then condensed with the air is sufficiently intense to light a small piece of tinder attached to the bottom of the piston.

Not only are spirits, æthers, oils, &c. convertible, as water is, into aeriform fluid, but also sulphur, phosphorus, mercury, and indeed all the metals and elementary substances;—some of them, however, requiring heats of great intensity.

The varieties of form, then, in the bodies on the face of this earth, may be considered accidental, as dependent on the temperature of the earth, and do not mark the permanent nature of the substances.

In the planet Mercury, which is near the sun, resin, tallow, wax, and many vegetable substances deemed by us naturally solid, would all be liquid, as oil is with us; and a certain mixture of tin, zinc, and lead, which with us is solid at common temperatures, but melts in boiling water, would there be always liquid like our quicksilver. Our water, oils, and spirits, would there be in a state of steam or air, and could not be known as liquids, except by cooling processes and compression, such



as we have lately learned to use for reducing our different airs to the form of liquids.

Again, in the cold planet Herschell, which is nineteen times farther from the sun than our earth is, water, if it exist, can be known only as a rock crystal, which fire would have to melt as it does glass with us : our oils would be as butters or resins, and quicksilver might be hammered, as lead or silver is with us.

On our own earth, near the equator, common sealing-wax will not retain impressions ; butter is oil in the day, and a soft solid at night ; and tallow candles cannot be used. And near our pole, in winter, the quicksilver from a broken thermometer is solid metal ; water must be melted by fire for use ; oils are solid, &c.

To judge then of the constitution of nature aright, we must always take extended surveys, and not allow prejudice to mislead us, as it did that Eastern potentate, who put a traveller to death for saying that he had visited remote northern countries, where water was sometimes to be seen solid like crystal, and sometimes white and fleecy, like feathers.—The ancients believed that there were just four elements concerned in forming our globe, with all upon it, viz. *earth, water, air, and fire*. What a contrast between former and present knowledge !

*Repulsion without sensible Heat.*

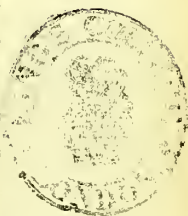
As we stated in a former paragraph that, besides general attraction, under the names of *gravitation, cohesion, capillary, and chemical attrac-*

*tion*, there are modifications which have the names of *electrical* and *magnetical* attractions; so we have now to remark, that, besides the general repulsion of heat just described, there are peculiarities which we call *electrical* and *magnetical repulsions*. Whether these depend altogether on different causes, or are only modifications of effect from the same cause, we cannot yet positively decide.

And it is a curious fact connected with the subject, that there seems to be a film of repulsion, so to express it, covering the general surfaces of all bodies, and preventing their meeting in absolute contact, even when they appear to the human eye so to meet. Were it not for this, things would be constantly approaching so closely to each other, that they would stick or cohere, in a way to disturb the common operations of nature. The following facts illustrate this superficial repulsion, and the means which art uses to overcome it for particular purposes.

Newton found that a ball of glass, or a watch-glass, laid upon a flat surface of glass, does not really touch it, and cannot be made to touch it by a force of even 1,000 pounds to the inch.

In like manner, when glass, stone, porcelain, or indeed almost any body is broken, we cannot make the parts cohere again by simply pushing them together in their former position. Where a union therefore between separate masses is desired, we are compelled to have recourse to various artifices.



A few cases in which cohesion is easily effected, were enumerated at page 18: the following are other instances of a different kind.

Gold leaf laid upon clean steel, and then forcibly struck by a hammer, coheres to the steel and gilds it permanently.

But iron can be made to cohere to iron, only by rendering both pieces red hot before hammering:—the process is called welding. Iron and platinum are the only metals that can be welded.

Tin and lead, in sheets, pressed together between the strong rollers of a flatting-mill, cohere.

The other metals require to be melted before the superficial repulsion gives way so as to allow separate quantities to cohere or run into one mass. It is thus, for instance, that gold, silver, lead, &c. are treated.

In many cases the substances are not such as can be melted (wood or marble, for instance), and then it is necessary to use some soft glue or cement. Cements must have strong attraction for both substances, and, when dry or cool, must be tenacious in themselves; solder, paste, common glue, mortar, &c. are the principal substances of this kind.

“ *Certain modifications of attraction produce the subordinate states, called crystal, porous, dense, &c.*” (Read the Analysis, page 7.)

It is a remarkable circumstance, that attraction, in causing the atoms to cohere so as to form solid masses, seems not to act equally all around each atom, but between certain sides or parts of one,

and corresponding parts of the adjoining ones ; so that when atoms are allowed to cohere according to their natural tendencies, they always assume a certain regular arrangement and form, which we call crystalline. Because in this circumstance they seem to resemble magnets, which attract each other only by their poles ; the fact has been called the polarity of atoms. It is the cause of several of the peculiarities above enumerated, as elasticity, &c.

“ *Crystallization*,” is exemplified in the following particulars :

Water beginning to freeze, shoots delicate needles across the surface ; these thicken and interweave until the whole mass has become solid, but the crystalline arrangement always remains. In most substances this arrangement is remarkably proved, by the forms of the surfaces left, when the mass is broken.

Moisture freezing on the window-pane in winter, exhibits a beautiful variety of arborescence.

A flake of snow, viewed in the microscope, is seen to be as symmetrically formed as a fern leaf or a swan’s feather.

If a piece of copper be thrown into a solution of silver in nitric acid, it is preferred by the acid to the silver, and is dissolved accordingly : the silver in the mean time, during its precipitation or separation, assumes the form of a singularly beautiful shrub or tree, resting on the remaining copper as its root. This appearance is called the *arbor Dianæ*.

Any metal which has been melted, when allow-



ed to cool again, slowly and at rest, becomes solid first on the outside of the mass. If, before the cooling be completed, the remaining liquid be poured from within, a curious internal crystalline structure, like grotto work, is seen. What is called the grain of a metal is the result of this crystallization.

Saltpetre, glauber salt, copperas (to use popular names), or any other of the many neutral salts, being dissolved in water, and the water being then allowed slowly to evaporate, re-appears in beautiful regular crystals, each salt having its peculiar forms, bounded by perfectly plane and polished surfaces. If any such crystal be broken in any part, the broken surface appears to the microscope as if regular layers of particles had been disturbed (as we see on a larger scale in a broken stack of bricks, or broken pile of shot in a battery yard), and the defect of the crystal will be exactly filled up by replacing it in the evaporating solution—proving that the ultimate particles are all of the same size.

All the precious stones are crystals, and can be well cut only parallel to their natural faces.

The basaltic pillars of the Giant's Causeway in Ireland, and of the Isle of Staffa, which appears like a garden supported on magnificent columns in the midst of the ocean, are natural crystalline arrangements of particles, equalling in regularity and beauty any human work, and in grandeur so far surpassing even the Egyptian pyramids, that superstitious conjecture naturally supposed them the work of giant architects.



It would be endless to go on enumerating crystalline masses, for nature's forms generally, in the inanimate creation, as well as in organized bodies, are regular and symmetrical; and what we see on earth of broken continents, and islands, and rocks, and wild alpine scenery, are the effects of subsequent convulsions, which have deranged a primitive and natural order.

Much ingenuity has been employed to account for the specific forms which different crystalline bodies assume; but the subject is not yet reduced to a state fitting it to be a part of this elementary study. A familiarity with the various figures, which the exact *science of measures* treats of, is required in the person who expects to pursue it with pleasure or advantage. The facts are extremely curious, and the scientific investigation of them may ultimately give important information respecting the intimate constitution of material nature.

“*Porous.*”—The crossing of the constituent crystalline needles or plates in bodies, causes them to be porous or full of small vacant spaces. In some cases these are visible to the eye, in many more cases, they are visible to the microscope, and in all, they are to be proved in some way.

Owing to the porosity arising from the new arrangement of atoms on solidifying, water and a very few other substances become more bulky in the change from the liquid to the solid state. Water then dilates with such force, as to burst the strongest vessels which art can provide, and in winter to split even rocks, where it has been

retained in their crevices ;—freezing water thus curiously producing effects which surpass those of exploding gunpowder. This agency of water contributes to the gradual breaking down of our alpine summits, and the falling of their destructive fragments into the vallies.

The stone called hydrophane (agate) is opaque, until dipped into water, when it absorbs into its pores one-sixth of its weight of the water, and afterwards give passage to light.

Into crystallized sugar, and various stones, much water will enter without increasing the bulk.

A kind of sand-stone, suitably shaped, forms an excellent filter or strainer for water.

Pressure will force water through the pores of the most solid gold ;—as was seen in the famous Florentine experiment, where a hollow, thick, golden ball, being filled with water and squeezed, to try the compressibility of water, was found to perspire all over. \*

The examples of porosity in animal and vegetable bodies are, however, the most remarkable.

Bone is a tissue of cells and partitions, as little solid as a heap of empty packing-boxes.

Wood is a congeries of parallel tubes, like bundles of organ pipes.—It has lately been proposed to prepare wood for certain purposes, as for making the great wooden pins or nails used in ship-building, by squeezing it to half its lateral bulk between very strong rollers, and thus making its density approach to that of metal.

A piece of wood sunk to a great depth in the ocean, and exposed to the pressure there, has its pores soon filled with water, and becomes nearly as heavy as stone. Thus it was with the boat of a whale-fishing ship, which had been dragged far under water by a whale, and which, on being afterwards drawn up, was supposed by the crew to be bringing a piece of rock with it.

A piece of cork in a strong close glass vessel nearly full of water, may be seen floating at the top; but if more water be then forcibly pumped into the vessel, the cork will be squeezed and reduced in size, until at last it becomes heavier than water and sinks. On water being afterwards allowed to escape, the cork will resume its bulk and will rise. A cork sunk 200 feet under water, will never rise again of itself.

A bottle of fresh water, corked and let down thirty or forty feet into the sea, often comes up again with the water saltish, although the cork be still in its place: the explanation being, that the cork, when far down, is so squeezed as to allow the water to pass in or out by its sides, but on rising resumes its former size.

“ *Density*,” or the quantity of atoms which exist in a given space, is very different in different substances.

A cubic inch of lead is forty times heavier than the same bulk of cork. Mercury is nearly fourteen times heavier than an equal bulk of water.

The density must depend on, first, the size or weight of the individual atoms; secondly, the

degree of porosity just now explained; and thirdly, the proximity of the atoms in the more solid parts which stand between the pores.

From many circumstances it appears, that the atoms even of the most solid bodies are nowhere in actual contact, but are retained in their places by a balance between attraction and repulsion—thus,

A body dilates or contracts, according as heat is added to or taken away from it.

A weight placed on any upright rod or pillar, shortens it and lessens its bulk, and if suspended from the bottom, lengthens it and increases its bulk,—the rod in both cases returning to its former dimensions when the weight is removed.

When a plank or rod is bent, the atoms on the concave side are for the time approximated, and those on the convex side are drawn more apart. It is remarkable in solid bodies, not only how precisely the balance between attraction and repulsion determines the relative position of the particles, but also how strongly; for any further separation of the particles is resisted by all the force which we call the tenacity or cohesion of the substance, and any nearer approach by all the force which we call the hardness or incompressibility.

Tin and copper when melted together to form bronze, occupy less space by one-fifteenth than when separate: proving that the atoms of the one are partially received into what were vacant spaces in the other. A similar condensation is observed in many other mixtures. A pound of water and a pound of salt, when mixed, form two pounds of

brine, but which has much less bulk than the ingredients apart. So also of a pound of sugar dissolved in a pound of water.

Water, and liquids generally, resist compression very powerfully, but yield enough to shew that the particles are not in contact. It is found that at 1,000 fathoms down in the sea the water is compressed by the superincumbent water so as to have bulk about a hundredth part less than it would have at the surface.

In aeriform masses the atoms are very distant, and hence the masses are more easily compressed. A pint of water on assuming the aeriform state, in which it is called steam, under ordinary pressure, acquires nearly 2,000 times its former bulk. A hundred pints of common air may be compressed into a pint vessel, as in the chamber of an air-gun; and if the pressure be much farther increased, the atoms will at last collapse and form a liquid. The heat which was contained in such air, and gave it its form, is squeezed out in this operation, and becomes sensible all around.

From these proofs of the non-contact of the atoms, even in the most solid parts of bodies; from the very great space obviously occupied by pores—the mass often having no more solidity than a heap of empty boxes, of which the apparently solid parts may still be as porous in a second degree, and so on; and from the great readiness with which light passes in all directions through dense bodies like glass, rock crystal, diamond, &c., it has been argued that there is so exceedingly little of really solid matter, even in the densest mass, that the



whole world, if the atoms could be brought into absolute contact, might be received into a nutshell. We have as yet no means of determining exactly what relation this idea has to truth.

The comparative *weights* of *equal bulks* of different bodies are called their *specific gravities*.

In thus comparing bodies, it was necessary to choose a standard; and water, as being the substance most easily procurable at all times and in all places, has been generally adopted.

The metal called platinum, the heaviest of known substances, is about twenty-two times as heavy as an equal bulk of water, and is therefore said to have specific gravity of 22—gold is nineteen times as heavy—mercury thirteen and a half—lead eleven—iron eight and a half—copper eight—common stones about two and a half—woods from a half to one and a half—cork one quarter, &c.

“*Hardness*” is not proportioned, as might be expected, to the density of the different bodies, but to the polarity of the atoms in them, that is, to the force with which the atoms hold their places in some particular arrangement.

Hardness is measured generally by the circumstance of one body being capable of scratching another.—It is here worthy of notice, however, that the powder or dust of a softer body will often, through an effect of motion to be described below, aid in wearing down or polishing one that is harder.

Gold though soft is four times heavier than the

hard diamond; and mercury, which is fluid, is nearly twice as dense as the hardest steel.

Diamond is the hardest of known substances. It cuts or scratches every other body, and is generally polished by means of its own dust.

Glass-cutters use a point of diamond as a glass-knife for dividing and shaping their panes.

Common flint also cuts glass, as is proved by the frequent scribblings on windows.

It is remarkable, that the preparation of iron, called steel, may either be soft like pure iron, or from being heated and suddenly cooled, in the process called tempering, may become nearly as hard as diamond. The discovery of this fact is perhaps second in importance to few discoveries which man has made; for it has given him all the edge-tools and cutting instruments by which he now moulds every other substance to his wishes. A savage will work for twelve months, with fire and sharp stones, to fell a great tree, and to give it the shape of a canoe; where a modern carpenter, with his tools, could accomplish the object in a day or two.

The project has lately been realized of engraving on plates of soft steel instead of copper, and afterwards tempering the steel to such hardness, that it may be used as a type or die to make its impression, not on paper, but on other plates of soft steel, or of copper; each of which is then equal in value to an original and distinct engraving. By this means the beautiful productions of art, instead of being limited to a comparatively small number of copies and of persons, may be

multiplied almost to infinity, becoming the cheap delight of all.

“*Elasticity*” is present in a mass when the atoms, cohering in a particular arrangement only, yield however, to a certain extent, when force is applied, but move back or regain their natural positions on the force being withdrawn.

Elastic bodies vary much as to the extent to which they yield without breaking, and as to the degree of perfection with which, after the bending, or displacement of atoms, they regain their former state. India rubber is extensively elastic, for it yields far; but it is not perfectly elastic, for when stretched much or often, it becomes permanently elongated. Glass, again, is perfectly elastic, for it will retain no permanent bend; but, unless in very thin plates indeed, or in fine threads, it will not bend far without breaking.

All hard bodies are elastic, as steel, glass, ivory, &c., and many soft ones, as caoutchouc, silk, a harp string, &c. The aeriform bodies are all perfectly elastic, as is rudely seen in a bladder filled with air, when squeezed, and allowed to expand again; and they will change volume to a very great extent. Liquids also are perfectly elastic, but to a small extent.

A good steel sword may be bent until its ends meet, and yet when allowed will return to perfect straightness.

A rod of bad steel, or of other metal, will be broken in bending, or will retain a bend.

An ivory ball, let fall on a marble slab, rebounds,

owing to the great elasticity of both bodies, nearly to the height from which it fell, and no mark is left on either. If the slab be wet, it is seen that the ivory or marble, or both, had yielded considerably at the point of contact; for a circular surface of some extent on the slab is found dried by the blow. The sudden expulsion of air from between the meeting surfaces might contribute to the effect, but the result is very nearly the same when the experiment is made in a vacuum. Billiard-balls scarcely lose even their polish by long wear, although the touching parts yield at every stroke.

A marble chimney piece long supported by its ends, is found at last to be bent downwards in the middle; and the bend is permanent.

A steel watch-spring, although so much and so constantly bent, resumes its original form when freed at the end of a century; but occasionally, without evident cause, while in action, it will suddenly give way.

Elasticity is a property of bodies of great utility to man, as in his time-pieces, carriage-springs, gun-locks, &c. &c.

“*Brittleness*” designates that constitution of a body where, with hardness, and elasticity perfect as far as it goes, the cohesion among the atoms exists within such narrow limits that a very slight change of position or increase of distance among them is sufficient to produce a rupture. A comparatively slight force, therefore, if sudden, breaks them. It belongs to most very hard bodies,

Glass scratches an iron hammer, proving that it

is harder than iron—yet glass is the very type of fragility; yielding to the stroke of soft wood, or indeed of almost any thing which can give a blow.

Steel, when tempered so as to be very hard, becomes brittle also. The steel chisels and tools with which artificers now shape the stones and metals, as they formerly did wood, require of course to be exceedingly hard; but they thereby lose in regard to the *extent* of their elasticity, and hence are frequently broken. Cast iron, which is much harder than malleable or wrought iron, is very brittle, while soft iron and steel are the toughest things in nature.

“*Malleable*,” or reducible into thin plates or leaves by hammering. This property, in opposition to elasticity and brittleness, belongs to bodies whose atoms cohere equally in whatever relative situations they happen to be, and therefore yield to force, and shift about among each other, without fracture or change of property, almost like the atoms of a fluid.

Gold is remarkably malleable, for it may be reduced to leaves of the thinness of  $\frac{1}{360,000}$  to the inch, or of  $\frac{1}{1,800}$  to a sheet of common paper. For gold-beaters the metal is first formed into rods, these are afterwards rolled or flattened into ribands; the riband is cut into portions, which are extended by hammering to great breadth and thinness, and which being again divided into portions, are hammered and extended to the thinness described.

Silver, copper, and tin may also be hammered



until very thin. Most other metals crack or are torn before the operation is carried far ; and some, on being struck, are broken at once, almost like glass.

“ *Ductile*,” or susceptible of being drawn into wire.

One might expect malleability and ductility to belong to the same substances and in the same degrees—but they do not. In ductile substances, as in malleable, the atoms seem to have no more fixed relation of position than in a liquid, but yet they cohere very strongly.

One end of a rod of iron, or other ductile metal, being reduced in size so as to pass through an opening in a plate of steel, is seized by strong nippers on the other side of the plate, and the whole rod is drawn through. It is thus reduced, of course, to the size of the opening, and is lengthened in a like proportion. By repeating the operation through smaller holes successively, a wire may at last be obtained of the size of a hair.

Dr. Wollaston’s ingenuity produced platinum wire finer than spider’s thread. He filled a space in the axis of a silver wire with small platinum wire. He then drew or reduced the compound piece to the smallest wire possible, and on dissolving the silver from the outside, he exposed to view the delicate filament of platinum.

The order in which metals may be ranged according to their ductility is, platinum, silver, iron, copper, gold, &c.

Melted glass has great ductility. The workers draw or spin it into threads, by merely attaching a point, pulled out from the mass, to the circum-

ference of a turning-wheel. A uniform thread then continues to be drawn out and wound upon the wheel, at the rate of 1,000 yards or more per hour. This glass thread, when lying together in quantities, resembles beautiful white hair, and when cut into bunches, it serves as an ornament to the female head, waving in the air like the delicate plume of a bird of paradise.

“ *Pliant.*” In bodies distinguished by this title, the cohesion is not destroyed by considerable change of direction among the particles, but there is little elasticity, and, unlike what happens in a ductile mass, the same atoms always remain together.

Of pliant things the chief are animal and vegetable fibres and membranes—as silk, bladder, lint, hemp, &c. &c.

“ *Tenacity*” means the force of cohesion among the atoms of any mass. It belongs more or less to all solids, and even to liquids.

This property varies much in different substances. Iron and its modification called steel possess it in the most remarkable degree.

The following table shews the comparative tenacity, or strength to resist pulling, of certain metals and woods. Supposing similar wires or rods of each to be used, and of such a size that the surface of a broken end or cross-section would be the one-thousandth of a square inch, the weights supported would be nearly as follows :

## METALS.

Cast Steel.....	134 lbs.
Best wrought Iron .	70
Cast Iron.....	19
Copper.....	19
Platinum .....	16
Silver .....	11
Gold.....	9
Tin .....	5
Lead.....	2

## WOODS.

Teak.....	13
Oak .....	12
Beech .....	12½
Ash .....	14
Deal .....	11

Iron, compared in this way, is five or six times stronger than oak.

Steel wire will support about 39,000 feet, that is,  $7\frac{1}{2}$  miles, of its own length.

Certain animal substances have great tenacity : as—the silk-worm's thread, which is our strongest connecting or sewing material, and has such flexibility united with its strength—the ligaments and tendons of the animal body, possessing at once such admirable strength, elasticity, and pliancy : these, when dried, and otherwise prepared, constituted the tough bow-strings of our remote forefathers—the hair or wool of animals, twisted into threads, and worked into the strong and beautiful textures of the loom—strips of animal intestine, prepared and twisted, forming the cords of harp

and violin, and in strength and uniformity rivaling the steel wires of keyed instruments.

The gradual discovery of substances possessed of strong tenacity, and which man could yet easily mould to his purposes, has been of great importance to his progress in the arts of life. The place of the hempen cordage of European navies is still held in China by twisted canes and strips of bamboo; and even the hempen cable of Europe, so great an improvement on former usage, is now rapidly giving way to the more complete and commodious security of the iron chain—of which the material to our remote ancestors existed only as an useless stone or earth. And what a magnificent spectacle is it, at the present day, to behold chains of tough iron stretched high across a channel of the ocean, as at the Menai Strait, between Anglesea and England, and supporting there an admirable bridge-road of safety, along which crowded processions may pour, regardless of the deep below, or of the storm; while under it, ships with sails full spread pursue their course, unmolested and unmolested!

SECTION II.—THE MOTIONS OR PHENOMENA OF THE  
UNIVERSE.\*

## ANALYSIS OF THE SECTION.

*The bodies or masses composing the universe may be at rest or in motion, and to change any present state, force proportioned to the quantity of the body and to the degree of change, is equally required, whether to give motion, to take it away, or to bend it:—a truth expressed by saying that matter has INERTIA, or figuratively, a stubbornness. Uniform straight motion, then, is as naturally permanent as rest. And the motion in any body, measured by its velocity, quantity of matter, and direction, is the measure of the amount and direction of any single force, or of the result of any combination of forces, which has produced it, as also of the force or momentum which the body can exhibit again when opposed or made to act itself as a cause of some new motion.*

*The great forces of nature, referred to by the two words ATTRACTION and REPULSION, acting upon INERT matter, produce the equable, accelerated, retarded, and bent motions which constitute the great phenomena of the universe.—Tides, currents, winds, falling bodies, &c. exemplify attraction.—Explosion, steam, collision, &c. exemplify repulsion. And as in every case of attraction or repulsion, two masses at least must be concerned, there is no motion or action in the universe, without an equal and opposite motion or re-action.*

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“ Motion ”

Is the term applied to the phenomenon of the changing of place among bodies.

Were there no motion in the universe it would be dead. It would be without the rising or setting sun, or river-flow, or moving winds, or sound, or light, or animal existence.

To understand the nature and laws of the mo-

\* The reader should here re-peruse the title and analysis at page 7.





tions or changes which are going on around him, is to man of the greatest importance, as it enables him to adapt his actions to what is coming in futurity, and often to interfere so as to control futurity, for his special purposes.

Motion, in any particular case, is described by referring to certain objects to mark place, and to some other motion chosen as a standard of velocity.—A man sitting on the deck of a sailing ship, has *common* motion with the ship: if walking on the deck, he has *relative* motion to the ship: but if he be walking towards the stern, just as fast as the ship advances, he is at rest relatively to the bottom or shore. A ship sailing against the tide, just as fast as the tide runs, is as much at rest relatively both to the earth and water, as if she were at anchor. *Absolute* motion is that which is relative to the whole universe, or rather to the space in which the universe exists. We have no means of ascertaining such: for although we know how fast our globe whirls upon its axis and wheels round the sun, we have no measure of the motion of the sun himself—revolving possibly round some more distant centre, but almost certainly having a progress in space, and carrying all the planets along with him.

Motion is called *rapid*, as that of lightning—*slow*, as that of the sun-dial shadow: both terms having reference to the ordinary intermediate velocities observed upon earth. It is called *straight*, or *rectilineal*, in the apparent path of a falling body—*bent*, or *curvilinear*, in the track of a body thrown obliquely—*accelerated*, in a stone falling

to the earth—*retarded*, in the stone thrown upwards while rising to the point where it stops before again descending.

“ *Owing to the INERTIA of bodies force is equally required to impart motion and to take it away.*”  
(Read again the last analysis.)

If a man put his hand to the crank of a heavy fly-wheel or grindstone, to turn it, he experiences a certain resistance, which however gradually yields to his effort, and he leaves the wheel whirling with velocity proportioned to the effort. If he then put out his hand again to stop the wheel, he experiences an opposite but similar resistance, which however, as before, gradually yields and he brings the wheel to rest. In the second case the effort required of him is less than in the first, by reason of the friction of the turning axle, and the resistance of the air in which the wheel moves,—obstructions which, when he was giving motion, opposed him, but when taking it away assisted him. That these obstructions cause the whole difference in such a case, and that they are the great reasons why all ordinary motions on earth seem to tend of themselves to cease, will be shewn in subsequent pages. It is the resistance overcome in moving the wheel or in stopping it, and occasioning an expenditure of force proportional to the mass and to the degree of change of state, which is called the INERTIA of the mass, or the *vis inertiae*, and sometimes, to help the conception of the student, the *stubbornness*, *sluggishness*, or *inactivity*; but no one of

these words can originally suggest to the mind all that is intended to be conveyed.

An exact measure of the amount of inertia is contained in the familiar fact, that a body let fall near the surface of the earth, falls rather more than 16 feet in the first second of time,—the well-known weight of the body, or force of terrestrial attraction acting upon it for one second, being just sufficient to overcome its inertia to the extent stated. Were the inertia of matter only half of what it is, a body near the earth would fall 32 feet in the second, instead of 16, as it equally would, if, with present inertia, the attraction of the earth were doubled. And were there no inertia, it would fall or pass through any height, however great, in one instant. As the amount of inertia thus determines the amount of other force required to give motion to a mass, so does it determine the amount of force required to destroy motion in a mass. A heavy cannon-ball, if wanting inertia, might be dispatched with the speed of lightning by the slightest force, but then the stiffness of a stalk of corn would suffice to arrest it; and while the ball, with the inertia now existing, takes the force of pounds of gunpowder to give it its usual motion, it may not be stopped, even by the cohesion of a block of granite, which accordingly it shivers to pieces. The numerous examples now to follow will prove the immense importance of *inertia* in the general operations of nature.

When the sails of a ship are first spread to receive the force or impulse of the wind, the vessel does

not acquire her full speed at once, but slowly, as the continuing force gradually overcomes the inertia of her mass. When the sails are afterwards taken in, she does not lose her motion at once, but slowly again, as the continued resisting force of the water destroys it.

Horses must make a greater effort at first to put a carriage into motion, than to maintain the motion afterwards. And a strong effort is required to stop a moving carriage. When a carriage, of which the body hangs from springs, is first moved, the body appears to fall back, and a person within seems to be suddenly forced against the back cushion. When the carriage is stopped again, the body swings forward, and if the stoppage be very sudden, a careless passenger may unwittingly pop his head through a front glass. These particulars prove the inertia, first of rest, and secondly of motion.

A man standing carelessly at the stern of a boat, when the boat begins to move, falls into the water behind ; because his feet are pulled forward, while the inertia of his body keeps it where it was, and therefore behind its support. The stopping of a boat, again, illustrates the opposite inertia of motion, by the man's falling forward.

An awkward rider on horseback may be left behind, when his horse starts forward suddenly ; or may be thrown off on one side by the horse starting to the other. A horse at speed, stopping suddenly, often sends his cavalier over his ears—as was mortifyingly experienced by a coxcomb who, on an old cavalry horse, chose to canter along



a foot-path, to the annoyance of the company, and whose horse, on hearing the word *halt* loudly addressed to it by a waggish officer of the regiment who happened to be there and to recognise it, suddenly stood, and got rid of its load. The mind or will of the beau had sinned against the law of propriety, but his body very perfectly obeyed the laws of inertia and gravity, by shooting forward in a parabolic curve to the earth.

A young man not yet accustomed to the whip, drove his phaeton against a heavy coach on the road, and then to his father foolishly excused his awkwardness, in a way which led to a prosecution of the coachman for furious driving. At the trial, the youth and his servant both deposed, that the shock of the coach was such as to throw them over their horses' heads, and thus lost the cause, by unconsciously proving, that the faulty velocity was their own.

A man jumping from a carriage at speed, is in great danger of falling forward, when his feet reach the ground; for his body has as much forward velocity, as if he had been running with the speed of the carriage; and unless he advance his feet like a running man, to support his advancing body, he must as certainly be dashed to the ground, as a runner whose feet are suddenly arrested. A man racing who receives a signal to stop, and a man jumping from a flying vehicle, must check their motion nearly in the same way.

A person wishing to leap over a ditch or chasm, first makes a run, that the motion thereby acquired



may help him over. A standing leap falls much short of a running one.

An African traveller saw himself followed by a tiger, from which he could not escape by running ; but perceiving that the animal was watching an opportunity to seize him by its usual spring or leap, he artfully led it to where the plain terminated in a precipice hidden by brush-wood, and he had just time to transfer his hat and cloak to a bush, and to retreat a few paces, when the tiger sprung upon the bush, and by the mortal inertia of its body, was carried over the precipice, and destroyed.

From a glass of water suddenly pushed forward on a table, the water is spilt or left behind ; but if the glass be already in motion, as when carried by a person walking, and if it then be suddenly stopped by coming against an impediment, the water is thrown or spilt forward.

A servant carrying a tray of glasses or china in the dark, and coming suddenly against an obstacle, hears all his freight slipping forward and crashing at his feet : and a too hurried departure with such a load causes equal destruction, on the opposite side.

The actions of beating a coat or carpet with a cane, to expel the dust ; of shaking the snow from one's shoes, by kicking against the door-post ; of cleaning a dusty book by knocking it against a table, or shutting it violently—all illustrate the same principle.

If a guinea be laid on a card which is already balanced on the point of the finger, a smart flip

or blow to the edge of the card will cause it to dart off, but the guinea, owing to its inertia, will remain resting on the finger,—its inertia being greater than the friction on it of the card passing from underneath it.

When we desire a person, with suspected disease of the brain, to shake his head, and tell whether and where he feels pain, we are doing nearly as if we touched the naked brain with the finger to find the tender part; for the inertia of the brain, when the skull is moved, causes a momentary pressure between it and the skull, almost equivalent, for the purpose desired, to such a touch.

This kind of pressure is sufficient to break and destroy tender wares—as glass or eggs—in packages which are too suddenly moved or stopped.

A weight suspended by a spring on ship-board is seen vibrating up and down as the ship pitches with the waves. It seems to fall as the ship rises, and to rise as the ship falls: but the motion is really in the ship, and the comparative rest is in the weight. A heavy weight so supported, and connected with a pump-rod, would work the pump.

Like the weight last mentioned, the mercury of a common barometer on ship-board is seen rising and falling in the tube; and until the important improvement was lately made, of narrowing one part of the tube to prevent this, the mercurial barometer was useless at sea. The explanation is, that the tube rises and falls with the ship, from being connected with it; but the mercury, which plays freely in the tube, and is supported by the

atmospheric pressure, tends, by its inertia, to remain at rest, and thus makes the motion of the ship apparent.

What happens to the mercury in the barometer tube on ship-board, indicates what happens to the blood in the vessels of animals under similar circumstances. In any long vein below the heart, when the body falls, the blood, by its inertia and the supporting action of the vessels, does not fall so fast, and therefore really rises in the vein: and as there are valves in the veins preventing return, the circulation is thus quickened without any muscular exhaustion on the part of the individual. This helps to explain the effect of the movement of carriages, of vessels at sea, of swings, &c., and of passive exercise generally, on the circulation, and leaves it less a mystery why these means are often so useful in certain states of weak health.

If a cannon ball were to break to pieces in its flight, its parts would still advance with the previous velocity. And thus, in the deadly contrivance of the Shrapnell-shell, which is a case containing hundreds of musket bullets, when these are scattered at the desired distance from the devoted body of men, they retain the forward velocity of the shell, and spread death around like the near discharge of a whole battalion of musquetry.

On the awful occasion of a ship in rapid motion being suddenly arrested by a sunken rock, all things on board, men, guns, and furniture, start from their places and dash forwards; while the onward inertia or mortal obstinacy of the hinder

parts of the ship, suffices to crush her bow against the rock.

“ *Motion as naturally permanent as rest.*”

From the instances now given, it is seen that a body at rest would never move if force were not applied, and that a body put into motion retains motion, at least for a time, after the force has ceased ; but there is a feeling, from common experience, that motion is an unnatural or forced state of bodies, and that all moving things, if left to themselves, would gradually come to rest. It is recollected that a stone projected comes to rest, or a wheel left moving, or a bowl rolled on the green, or the waves heaving after a storm—and, in a word, that there is no perpetual motion on earth.

On more attentive consideration, however, it may be perceived that there are prodigious differences in the duration of motions, and that the differences are always exactly proportioned to evident causes of retardation, and chiefly to *friction* and the *resistance of the air*.

Friction is the resistance which bodies experience when rubbing or sliding upon each other ; and however much it may be diminished by art, it can in no case be annihilated. Air-resistance again, to motions going on in air, is of the same nature as water-resistance to motions going on in water, only less in degree : and as advancing science has shewn the true nature of our atmosphere, the amount of this resistance is perfectly ascertained.

A smooth ball rolled on the grass soon stops—

if rolled on a green cloth over a smooth plank it goes longer—on the bare plank, longer still—on a smooth and level sheet of ice, it hardly suffers retardation from friction, and, if the air be moving with it, will reach a distant shore.

Two little windmill-wheels set in motion together with equal velocity, but of which one has the flat sides of the vanes turned to their course, and the other the edges, if moving in the air, will stop at very different times, but if tried in a vessel from which the air has been removed, they will both go much longer, and will then stop exactly together.

As it is to facilitate the motion of fishes in the water, that they are of sharp form before and behind; so it is to facilitate the motion of birds in the air that they have somewhat of similar form.

A large spinning top, with a fine hard point, set in motion in a vacuum, and on a hard smooth surface, will continue turning for hours.

A pendulum moving in a vacuum has only to overcome slight friction as its point of suspension, and therefore, if once put in motion, will vibrate for a day or more.

But it is in the celestial spaces that we see motions completely freed from the obstacles of air and friction—and there they seem eternal.

Had the human eye, unassisted, been able to descry the four beautiful moons of Jupiter, wheeling around him for these thousands of years, with such unabated regularity, and which now form, to the telescope of the astronomer, a perfect and



magnificent time-piece in the sky, or had science long proved that the velocity imparted to our globe, when first launched into its present orbit, still wheels it along as swiftly as in the days of the first man, this error or prejudice, that motion is always tending to rest, would never have arisen.

Indeed, had these, and other such truths, been long familiar to the common mind, the opposite prejudice might as well have obtained, that motion is the natural state, and rest a forced or unknown state. We know of nothing which is absolutely at rest. The earth is whirling round its axis and round the sun ; the sun is moving round its axis and round the centre of gravity of the solar system, and, possibly, round some more remote centre in the great universe, carrying all his planets and comets about his path.

If there were any natural tendency in moving bodies to stop, a thing floating in a trough of water, on board a sailing ship, should always be found at the end of the trough nearest the stern ; and in all the seas and lakes of the earth, the floating things should be accumulated on the western shores, because the surface of the earth is always turning to the east. We know that neither of these suppositions is truth. A man on board a moving ship can throw any body just as far towards the bow as towards the stern ; although in the two cases the velocity, as regards the earth, is so different.

Ignorance of the law of motal inertia led a story-telling sailor to assert, as a proof of the speed of his favourite ship, that when a man one day fell

from the mast-head, the ship had passed from under him before he reached the deck : the fact, in such a case, being, that he must have fallen on the same part of the deck, whether the ship were in motion or at rest, because his body had just the motion or rest which belonged to the ship.

Another equally sapient man, reflecting that the earth turned round once in twenty-four hours, proposed rising in a balloon, and waiting aloft until the country which he desired to reach should be passing under him.

“ *Motion naturally uniform.*” (See the Analysis.)

It is only repeating that a body can neither acquire motion nor lose motion without a cause, to say that free motion must be *uniform*.

The perfect uniformity of undisturbed motion, is proved by every fact observed in the universe. If any continued motion, as of a planet for instance, be found at one time to have a certain relative velocity to some other continued motion, the same relation is found always to hold : or deviations from perfect uniformity are exactly proportioned to the disturbing causes. Thus we can foretell the exact time of an eclipse, a thousand years before its occurrence.

Had motion not been in its nature uniform, man could have formed no rational conjecture or anticipation as to future events ; for it is by assuming, for instance, that the earth will continue to turn uniformly on its axis, that he speaks of *to-morrow* and of *next week*, &c., and that he makes all his

arrangements for future emergencies : and were the coming day, or season, or year, to arrive sooner or later than such anticipation, it would throw such confusion into all his affairs, that the world would soon be desolate.

To calculate futurities, then, or to speak of past events, is merely to take some great uniform motion as a standard with which to compare all others ; and then to say of the remote event, that it coincided or will coincide with some described state of the standard motion. The most obvious and best standards are the whirling of the earth about its axis, and its great revolution round the sun. The first is rendered very sensible to man by his alternately seeing and not seeing the sun, and it is called *a day* ; the second is marked by the succession of the seasons, and it is called *a year*. The earth turns upon its axis nearly 365 times while it is performing one circuit round the sun, and thus divides the year into so many smaller parts ; and the day is divided into smaller parts, by the progress of the earth's whirling being so distinctly marked, in the constantly varying direction of the sun, as viewed from any given spot on the face of the earth.—When advancing civilization made it of importance for men to be able to ascertain with precision the very instant of the earth's revolution, connected with any event, various contrivances were introduced for the purpose ; as,—sun-dials, where the shadow travels progressively round the divided circle ;—the uniform flux of water through a prepared opening ;—the flux of sand in the common hour-

glass, &c. But the great triumphs of modern ingenuity are those astronomical clocks and watches, in which the counted equal vibrations of a pendulum, or balance-wheel, have detected periodical inequalities even in the motion of the earth itself, and have directed attention to unsuspected disturbing causes, important to be known.

It is the natural uniformity of undisturbed motion which causes any number of bodies moving together, as the furniture of a sailing ship, to appear among themselves as if at rest,—no one tending to pass before, or to fall behind, or to move to one side of another. For the same reason a person who is moving with such bodies is absolutely insensible of his uniform progression, and knows it only by reasoning from such facts as the changing appearances of other objects around which do not share the motion, the rushing of the waves or wind, &c. When a ship is becalmed at sea, she may, as numberless sad accidents have proved, be carried by rapid currents in any direction, without one of the crew suspecting that she has motion at all; and if the suspicion do arise, the truth can be come at only by such means as the sounding line, where the bottom can be reached, or careful observation of the heavenly bodies where it can not. A man in the hold of a ship in a river or tidesway cannot say whether the rushing of water, which he hears from without, be a rapid tide passing the ship at anchor, or the effect of the ship's advance in the river. A man in a balloon going 80 miles an hour, knows not in what direction he is moving, nor indeed



that he is moving at all, but by observing the objects below.

This explains why men are not sensible of the motion of the earth itself, which they know however to be turning round its axis once in twenty-four hours, and therefore to have its surface near the equator moving with a speed of more than 1,000 feet per second ; and as in the case of a ship or balloon, there would be no difference of sensation whether the speed were of one mile per hour or of 10 or 100, so in the case of the earth, there would be none whether it turned as now, once in twenty-four hours, or, like the planet Jupiter, once in ten. A hunter among the hills, who during the heat of noon, rests and contemplates around him a sublime scene of solitude and silence, may little think that if amidst that apparent repose of nature he were for a moment lifted up from the earth and held *at rest* above its surface, he would see its face of hill and dale sweeping past beneath him at the prodigious rate of fifteen miles an hour, on account solely of the whirling of the earth.

The fact that a cannon ball can be shot just as far upon the surface of the earth, eastward, in the direction of the earth's motion, as westward, against it, illustrates the truth, that whatever *common* motion objects may have, it does not interfere with the effect of a force producing any new relative motion among them. All the motions seen on earth are really only slight differences among the common motions : as in a fleet of sailing ships, the apparent changes of place among them are in



reality only slight alterations of speed or direction, in their individual courses.

A man continuing to throw upwards a ball or orange, or several of them at once, and to catch and return them alternately, uses no difference of art as regards them, whether he be standing on the earth and whirling with it, or on a sailing ship's deck, or in a moving carriage, or on a galloping horse's back. He and the oranges have always the same forward common motion. And when a man, standing on a galloping horse, leaps through a hoop held across his course, he does not leap forward—for this would throw him over the horse's ears—but merely jumps up, and allows his motal inertia to carry him through.

The reason that a lofty spire or obelisk stands more securely on the earth than even a short pillar stands on the bottom of a moving waggon, is, not that the earth is more at rest than the waggon, but that its motion is uniform.—Were the present rotation of our globe to be arrested but for a moment, imperial London, with its thousand spires and turrets, would, by the motal inertia, be swept from its valley towards the eastern ocean, just as loose snow is swept away by a gust of wind.

*“ Force is required to bend motion.”*

If a body moving freely cannot vary its velocity without a cause, neither can it vary its course without a cause; and free motion, therefore, is *straight* as well as *uniform*.

A ball shot directly up or down gives men their simplest idea of straight motion.

A bullet or arrow, projected horizontally, is gradually drawn downwards by the attraction of the earth, but it deviates neither to the right hand nor to the left.

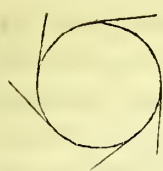
William Tell, trusting to the natural straightness of motion, obeyed the tyrant's order, and shot at an apple placed on his child's head.

And the right eye of Philip of Macedon is said to have been destroyed by an arrow which brought a label on it, telling its destination.

Riflemen shooting at a target, hit the very spot they choose to aim at.

A stone in a sling, the moment it is set at liberty, darts off as straightly as an arrow from the bow-string or a bullet from a gun-barrel, and it is only because the point of its circle, from which it should depart, cannot in practice be accurately determined, that the same sure aim cannot be taken with it.

A body moving in a circle, then, or curve, is constrained to do what is contrary to its inertia. A person, on first approaching this subject, might suppose that a body, which for a time has been constrained to move in a circle, should naturally continue to do so when set at liberty. But on reflecting that a circle is as if made up of an infinite number of little straight lines, and that the body moving in it has its motion bent at every step of the progress, the reason is seen why constant force becomes necessary to keep it there, and force just equal to the inertia with which the body tends, at every point of the circle, rather to pursue the straight line, called a tangent, of which that point, as seen in the figure, is the commencement, than



the circle itself. The force required to keep the body in the bent course is called *centripetal* or centre-seeking force ; while the inertia of the body tending outwards, that is, to move in a straight line rather than in a curve, is called the *centrifugal* or centre-flying force ; and the term *central forces* is applied to both.

A sling-cord is always tight while the stone is whirling : and its tension is of course the measure, both of the centripetal and centrifugal force. A means, then, of measuring the tension of a sling-cord would experimentally demonstrate the amount of centrifugal force ; and such a means we possess in the contrivance called the “ whirling table,” upon which a loaded sling, or any mass with a string attached to it, may be placed to revolve, at any desired distance from the centre, and with any desired velocity, while the string passing over a pulley at the centre, is made to lift weights proportioned to the outward dragging of the revolving mass. By this apparatus it is found, as would be expected, that centrifugal force—in other words, the force with which the inertia of moving matter resists the bending of its course from straight to circular, is proportioned, first, to the quantity of matter moved—every separate particle having its own inertia ; second, to the size of the circle or orbit described in the same time—a body moving in a circle of double diameter for instance, having to be forced inwards from the tangent, at every departure, twice as far in a given time ; third, that with a double revolution in the same time,

the centrifugal force is not double but quadruple (a corresponding proportion existing for other velocities), because, not only are there twice as many bendings or angular departures from the tangent for the two circles as for one, requiring, as may be said, twice as many tugs or impulses of the centripetal force, but every impulse must be made with double energy, for it has to drive the mass inwards through the required distance in half the time ; and twice as many impulses, every one being twice as strong, make a quadruple amount of force on the whole ; fourthly and lastly, it is found, agreeing with the relation between inertia and terrestrial gravity described at page 52, that a body revolving, for instance, in a circle of four feet diameter, that it may have centrifugal force just equal to its weight, requires to complete its revolution in one second and a half of time. This and similar facts will be more particularly considered when we come to treat of the motions of the planets round the sun. This analysis of central forces will suffice to excite in the student a due interest touching the kindred phenomena now to be described.

Bodies laid on a whirling horizontal wheel, are readily thrown off.

In a corn-mill, the grain, after being admitted between the stones through an opening in the centre of the upper stone, is then kept turning round between them, and is, by its centrifugal force, always tending and travelling outwards until it escapes as flour from the circumference.

A man, if he lie down on a turning millstone

with his head near the edge, falls asleep, or dies of apoplexy, from the new pressure of blood on the brain.

A wet mop, or bottle-brush, made to turn quickly on its handle<sup>s</sup> as an axis, throws the water off in all directions, and soon dries itself.

Sheep, in wet weather, thus discharge the water from their fleeces, by a semi-rotatory shake of the skin. Water-dogs, on coming to land, dry themselves by the same action.

A tumbler of water, placed in a sling, may be made to vibrate like a pendulum with gradually increasing oscillation, and at last to describe the whole circle, and continue revolving about the hand, without spilling a drop :—the water, by its inertia of straightness, or centrifugal force, tending more away from the centre of motion towards the bottom of the tumbler, even when that is uppermost, than towards the earth by gravity.

As solid bodies laid on a whirling table are thrown off, so water in a vessel caused to spin round in any way, as on the centre of a horizontal wheel, instead of lying at the bottom, is raised up all round, against the sides of the vessel.

Water, poured obliquely into a funnel, runs round the interior of it, and often leaves an open passage of air all the way down through it, as if there were merely a lining of water to the funnel. The centrifugal force of the turning water, is a chief reason of this phenomenon :—another reason will be considered further on, under the head of atmospheric pressure.

Great whirlpools at sea, and smaller ones, or



eddies in rivers, occur whenever a current is obliged suddenly to bend, as in rounding a point of land or a rock, or in meeting and mingling with a contrary current. The water, by tending to continue its straight motion, falls in behind the obstruction, reluctantly as it were, and leaves there a pit surrounded by a liquid revolving ridge. Charybdis in the Mediterranean, and the great whirlpool off the Norwegian coast, are noted examples.

It is owing to the centrifugal force in any bending part of a stream of water, that is to say, to the tendency away from the centre of the curvature, that when a bend has once commenced, it increases, and is soon followed by others, until that complete serpentine winding is produced, which characterizes most rivers in their course across extended plains. The water being thrown by any cause to the left side, for instance, wears that into a curve or elbow, and, by its centrifugal force, acts constantly on the outside of the bend, until rock or higher land resist the gradual progress; from this limit being thrown back again, it wears a similar bend to the right hand, and after that another to the left, and so on.

Carriages are often overturned in quickly rounding corners. The inertia carries the body of the vehicle in the former direction, while the wheels are suddenly pulled round by the horses into a new one. A loaded stage-coach running south, and turned suddenly to the east or west, strews its passengers on the south side of the road. Where a sharp turning in a carriage-road is unavoidable,

the road towards the outside of the bend should always be made higher than at the inside, to prevent such accidents.

A man or a horse turning a corner at speed, leans much inwards or towards the corner, to counteract the centrifugal force, that would throw him away from it.

In skating with great velocity, this leaning inwards at the turnings becomes very remarkable, and gives occasion to the fine variety of attitudes displayed by the expert; and if a skater, in running, finds his body inclined to one side, and in danger of falling, he merely makes his skait describe a slight curve towards that side, when the tendency of his body to move straightly, or its centrifugal force, refusing to follow in the curve, allows the foot to push itself again under the body, and to restore the perpendicularity. Skating becomes to the intelligent man an intellectual, as well as a sensitive or bodily treat, from its exemplifying so pleasingly the laws of motion.

The last example explains, also, why a hoop rolled along the ground goes so long without falling: if it incline to one side, threatening to fall, by that very circumstance the part touching the ground is made to bend its course to that side, and as in the case of the skater who turns his foot, the supporting base is again forced directly under the mass of the body.

A coin dropt on the table or floor, often exhibits the same phenomenon. It is said to run and hide itself in the corner. Just before falling, if not obstructed, it describes several turns of a de-

creasing spiral, the minute examination of which is a pleasing mathematical exercise.

The reason also why a spinning top stands, will be understood here. While the top is quite upright, the extremity of its peg, being directly under its centre, supports it steadily, and although turning so rapidly, and with much friction, has no tendency to move from the place ; but if the top incline at all, the *edge* or *side* of the peg, instead of its very *point*, is in contact with the floor, and the peg then becoming as a turning little roller, advances quickly, and describes a curve somewhat as a skater's foot does, until it come directly under the body of the top as before. It thus appears that the very fact of the top inclining, causes the point to shift its place, and to continue moving until it come again directly under the centre of the top. It is remarkable that even in philosophical treatises of authority the standing of a top is still vaguely attributed to *centrifugal force*. And some persons believe, that a top spinning in a weighing scale, would be found lighter than when at rest ; and others most erroneously hold that the centrifugal force of the whirling, which of course acts directly away from the axis, and quite equally in all directions, yet becomes, when the top inclines, greater upwards than downwards, so as to counteract the gravity of the top. The way in which centrifugal force really helps to maintain the spinning of a top is, that when the body inclines or begins to fall in one direction, its motion in that direction continues, until the point describing its curve, like the foot

of a skaiter, has forced itself under the body again.

By reason of centrifugal force also, it is easier to do feats of horsemanship in a small ring, as at our theatres, that if the animal were running on a straight road. We see the man and horse always inclining inwards, to counteract centrifugal force, and if the rider tend to fall inwards, he has merely to quicken the pace, if to fall outwards, he has to slacken it, and all is right again.

If a pair of common fire-tongs, suspended by a cord from the top, be made to turn by the twisting or untwisting of the cord, the legs will separate from each other with force dependent on the speed of rotation, and will again collapse when the turning ceases. Mr. Watt adapted this fact most ingeniously to the regulation of the speed of his steam-engine. His *steam-governor* may in truth be described as a pair of tongs with heavy balls at the ends, to make their opening more energetic, attached to some turning part of the machine. If the engine move with more than the assigned speed, the balls open or fly asunder beyond their middle station, and by a simple contrivance are then made to act on a valve which contracts the steam-tube; on the contrary, with too slow a motion, they collapse and open the valve.

A half-formed vessel of soft clay, placed in the centre of the potter's table,—which is made to whirl, and is called his wheel,—opens out or widens merely by the centrifugal force of its sides, and thus assists the worker in giving its form.

A ball of soft clay, with a spindle fixed through



its centre, if made to turn quickly, soon ceases to be a perfect ball. It bulges out in the middle, where the centrifugal force is great, and becomes flattened towards the ends, or where the spindle issues.

This change of form is exactly what has happened to the ball of our earth. It has bulged out seventeen miles at the equator, in consequence of its daily rotation, and is flattened at the poles in a corresponding degree.—A mass of lead that weighs one thousand pounds at our pole, weighs about five pounds less at the equator, by reason of the centrifugal force.

In the planets Jupiter and Saturn, of which the rotation is much quicker than of our earth, the middle or equator bulges out still more—even so as to offend an eye which expects a perfect sphere.

If the rotation of our earth were seventeen times faster than it is, the bodies or matter at the equator would have centrifugal force equal to their gravity, and a little more velocity would cause them to fly off altogether, or to rise and form a ring round the earth like that which surrounds Saturn. Saturn's double ring seems to have been formed in this way, and is now supported chiefly by the centrifugal force of the parts. Were it to crumble to pieces, the pieces might still revolve, as so many little satellites. His true satellites are only more distant masses sustained in the same manner. And our earth and the other primary planets have the same relation to the sun that these satellites have to Saturn—all being sustained by



an admirable balance between centrifugal force and gravity.

*“ The quantity of motion in a body measured by the velocity and quantity of matter.”*

If a single atom of matter were moving at the rate of one foot per second, it would have a definite quantity of motion expressed by these words; and if it were moving ten feet per second it would have ten times the quantity. Again, in a mass consisting of many atoms, the quantity of motion would be still as much greater, as there were more atoms in it than one.

By experiment it is found, that if a ball of soft clay of one pound, suspended by a cord as a pendulum, be allowed to fall, with a velocity of ten feet per second, against a ball of nine pounds suspended in the same way, but at rest, the two, after contact, will start together at the rate of one foot per second, the original quantity of motion being then diffused through ten times the quantity of matter, and therefore exhibiting only one-tenth of the velocity.

A cannon-ball of a thousand ounces, moving one foot per second, has thus the same quantity of motion in it as a musket-ball of one ounce, leaving the gun-barrel with a velocity of a thousand feet in the second.

*“ The quantity of motion in a body is the measure of the force which produced it ;”*

The experiment of the balls of clay mentioned above furnishes one instance of this truth. Again, a body falling for ten seconds, acquires ten times

as much velocity as by falling for one second ; its motion thus measuring the force of gravity which has been exerted upon it.

When a large body or mass of many atoms falls, it of course has as much more motion than a smaller body, as there are more atoms in it than in the smaller ; but as gravity acts equally on every atom, the force causing either body to fall is still exactly indicated by the quantity of motion in it.

A large body or a mass of many atoms falls, where there is no impediment, with the same velocity as a smaller body or a single atom ; for gravity pulls equally at each atom, and must overcome its inertia equally, whether it be alone or with others.

This remark contradicts the popular opinion, that a large and heavy body should fall to the earth much faster than a small and light one ; an opinion which has arisen from our constantly seeing such contrasts, as the rapid fall of a gold coin, and the slow descent of a feather. The true cause of the contrast is, that the atoms of the feather are much spread out, so as to be more resisted by the air than those of the gold. If the two be let fall together in a vessel from which the air has been extracted—as in the common air-pump experiment,—they arrive at the bottom in exactly the same time : and even in the air, if the coin be hammered out into gold leaf, it will fall still more slowly than the feather. One brick dropped from a height, because its motion is not much affected by the air, reaches the earth very

nearly as soon as ten bricks let fall near it, whether they be connected or separate—as a single horse may reach the goal as soon as ten horses galloping abreast.

A man's force will move a small skiff quickly, a loaded barge very slowly, and a large ship in a degree scarcely to be perceived. In each case however, the quantity of motion may be the same, and a true measure of the force which produced it.

A ball of one pound weight, impelled by a given force, moves twice as fast as a ball of two pounds impelled with the same ; yet, although the velocities are different, the quantities of motion, as ascertained by the rule already given, are equal, and indicate an equality of producing force.

*“ The quantity of motion in a body is the measure also of the force or momentum which it can exhibit again.”* (See the Analysis, page 49.)

Bodies, owing to their inertia, may be regarded as passive reservoirs of force or motion, always ready to return as much as they have received. *Momentum* is the name given to the motion in a body, with reference to the production by it of new motions or the overcoming of resistances, and is but another term for the *quantity of motion*.

A cannon-ball, according to the quantity of motion in it, may have only the force or momentum that will bruise a plank, or it may have enough to penetrate a tree, or even to shoot its rapid way through a block of the hardest stone.

A block of wood, floating against a man's leg with moderate velocity, would be little felt ; but

a loaded barge, coming at the same rate, and pressing it against the quay, might break the bones; a large ship, again, although moving no faster, would crush his body against any fixed obstacle; and an island of ice, opposed in its approach to another, even by a first-rate man of war, would destroy it, as meeting barges destroy a floating egg-shell.

A hail-stone falling, strikes rudely; a stone rolled from a height, as of old, by the besieged against besiegers, may carry death with it to many; an avalanche, breaking from its hold on a mountain steep, may sweep away a village.

To meeting bodies, the shock is the same, whether the motion be shared between them or be all in one.

If a running man come against a man who is standing, both receive a certain shock. If both be running at the same rate in opposite directions, the shock is doubled. In some such cases, as where swift skaters have met, the shock has proved fatal.

The meeting fists of boxers not unfrequently dislocate or break bones.

A man's skull is fractured as certainly by its being dashed against a tree or beam, while he is on a galloping horse, as by the blow of a similar beam coming upon him with the velocity of the horse.

When two ships in opposite courses meet at sea, although each may be sailing at a moderate rate, the destruction is often as complete to both, as if

with a double velocity they had struck on a rock. Many melancholy instances of this kind are on record. In the darkness of night a large ship has met one smaller and weaker, and, in the lapse of a few seconds, have followed the shock of the encounter, the scream of the surprised victims, and the horrible silence when the waves had again closed over them and their vessel for ever.—In November 1825, on the coast of Scotland, the Comet steam-boat was thus destroyed, and carried to the bottom with her about seventy passengers, into whose ears the drowning water rushed before the sounds of arrested music and joy had died away.

*“ Direction of the force or forces producing motion.”*

When only one force acts on a body, the body obeys in the exact direction of the force.

A ball floating in water, or lying on smooth ice, is driven exactly south by a wind blowing to the south. A bullet issues from the mouth of a cannon, in the direction of the axis of the cannon—which is, as the force impels it.

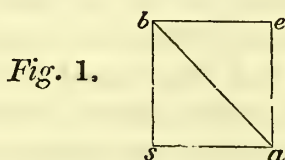
When two or more forces, not in the same direction, act upon a body at the same time, as it cannot move two ways at once, it holds a middle course between the directions. This course is called the *resulting direction*, viz. resulting from the *composition of the forces*.

A ball or ship moving south by a direct wind, may, at the same time, be carried east, just as fast, by a tide or current moving east : every instant,



therefore, it will go a little *south* and a little *east*, and really will describe a middle line pointing *south-east*.

These particulars may be well represented on paper, as by fig. 1 : where



*b* is the original place of the ball or ship, *e* the east, *s* the south, and *b a* the middle line pointing to the south-east, and shewing the true course of the vessel. This figure is called the *parallelogram of forces*, and is an important help to the understanding of many facts in natural philosophy. The minute investigation of the subject belongs to the *science of measures*, or technical mathematics; but the general truths are quite intelligible to common sense, or the mathematics of common experience.

When two forces act upon a body, like the wind and tide in the last example, the result is the same, whether they act together or one after the other. For instance, if the wind drive a vessel one mile south, as from *b* to *s*, fig. 1, and immediately afterwards the tide drive it one mile east, as from *s* to *a*, the vessel will be in the same place at last, viz. at *a*, as if she had been driven at once south-east, in the line *b a*, by the simultaneous action of the two. Therefore by drawing the lines *b s* and *b e* to represent the force and direction of the two causes of motion, and by then adding one of

them, or an equivalent, to the end of the other, as  $sa$  to  $bs$ , or  $ea$  to  $be$ , the square or parallelogram is sketched, of which the middle line, or *diagonal*, as it is called, shews the *resultant* of the forces, and the true course of the body obeying them.

What is thus true of the effect of continued forces like wind and tide, is true also of momentary impulses, like the blows of clubs simultaneously striking a ball, or of two billiard-balls striking a third.

When the forces exactly cross each other, and are equal, as in the case of the ship above supposed, the figure becomes a square, as at fig. 1; but if one of the forces be greater than the other the figure becomes oblong, as at fig. 2; if the forces cross obliquely, the figure becomes as at fig. 3;

Fig. 2.

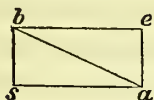


Fig. 3.

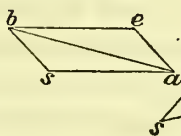
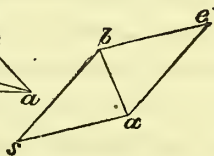
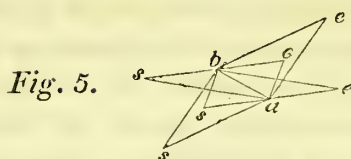


Fig. 4.



and if they cross in an opposing direction, it will be as at fig. 4. In all the cases, however, the diagonal still shews the *result*. It is evident that the same line may be the diagonal of many figures, as seen in  $ba$  at fig. 5; and therefore, that very different degrees and directions of combined forces may produce the same *result*.



Forces crossing each other so obliquely as to be represented by lines drawn in almost opposite directions, would form a parallelogram having scarcely any breadth, that is to say, the diagonal would approach to nothing; shewing thus, that opposing forces neutralize or destroy each other. In fig. 4, by reason of this crossing, the *resultant* is less than either of the constituents. And for the same reason, when forces cross so acutely as to advance nearly parallel to each other, the *resultant* is longer than either, as seen in fig. 3. Forces directly opposed, or entirely agreeing in direction, give as their resultant their difference or their sum.

Forces crossing each other directly, or at right angles, as is true of the exactly eastward force  $b e$ , and the exactly southward force  $b s$ , in figures 1 and 2,—do not in the slightest degree neutralize or alter each other, for the body when arrived at  $a$  is just as far east as it would be at  $e$ , and as far south as it would be at  $s$ . This explains why the progressive motion of the planets in their orbits is not at all affected by the directly crossing centripetal force of gravity which keeps them at their due distances from the sun.

In all cases where the two crossing forces are equal, with whatever obliquity they cross, the resulting direction must be midway between them.—Thus a boat impelled by oars, goes straight,

although the direction in which the oars act is constantly changing; because the changing obliquity of the force is always the same on both sides.—This explains also why a bird flying, or a man swimming, holds a perfectly straight course, although in both cases the direction of the impelling forces is constantly varying.—And it explains why a body suspended, as a plummet, or falling to the earth, as an apple does from a tree, is always in a line towards the centre of the earth: for, while the part of the earth immediately under the body is pulling it straight down to the centre, the action of parts on any one side of the perpendicular is exactly counterbalanced by the action



of corresponding parts on the opposite side; and the perpendicular is still the diagonal or middle line of every pair of attracting parts. In this figure *b a* represents the common diagonal. In

speaking of the attraction of our earth, therefore, which really is the united attraction of all the individual atoms, we may always consider it as a single force acting towards the centre of the earth.

When a body is carried below the surface of the earth its weight becomes less, because the matter then above it is drawing it up, instead of down, as before. A descent of a few hundred feet makes a sensible difference, and at the centre of the earth, if man could reach it, he would find things to have no weight at all; and there would be neither up nor down, because bodies would be attracted equally in all directions.

When more than two forces act on a body, the

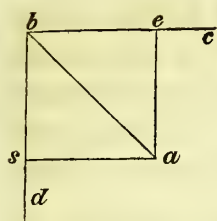


resulting direction may be found, first of two, and then of the last *resultant* with each of the others successively:—or the forces may be represented on paper by lines tacked together, of which one denotes the strength and direction of each: the extremity of the last line will mark the place of the body after being acted upon by the combined forces. A sailor, to know the true place of his ship and the course which she has steered, considers, first, the forward progress as found by the log, then the leeway or sideward motion produced by a cross wind, and then the effect of any tide or current in which he may be sailing.

*Resolution of Forces* is a phrase pointing to another important use of such parallelograms or figures as have just been described, *viz.* the enabling us, when any force or motion is given, to find the forces or motions in any other directions of which it may be the *resultant*, and those into which it may itself be resolved.

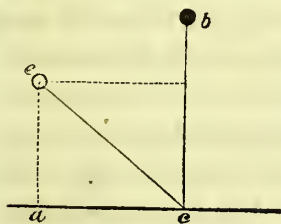
Thus, if a line  $ba$  (in any of the preceding figures 2, 3, 4, &c.) represent a force or motion, and the line  $bs$  represent one of two elements composing it, we have but to complete the parallelogram  $bsae$  to obtain the other line,  $be$  representing the only other force or motion which combined with the first element, can produce the given resultant.—If a ship pass from  $b$  to  $a$  (fig. 3) while sailing through the water eastward, a distance expressed by  $be$ , she must at the same time have been carried by a tide or current to the distance and in the direction marked by the line  $bs$ .





Again, if a line be given representing a single force, or motion, as  $ba$ , and if it be desired to know how much there is in this capable of acting in another direction, as  $bd$ ; it is only necessary to draw a line in the direction  $bd$ , from the commencement of  $ba$ , and to cut such line by another drawn directly upon it—or at right angles to it, as the term is, from the other end of  $ba$ : the length of  $bd$ , so cut off, *viz.*  $bs$ , shews the proportion required.

It is thus that a sailor, who knows how far he has sailed in any oblique direction, finds out how much he has gone north and east, or south and west; in other words, finds out the difference of latitude and longitude between his present place and a former one. In the above figure,  $ba$  may represent the course and distance sailed,  $bs$  the difference of latitude, and  $be$  the difference of longitude.

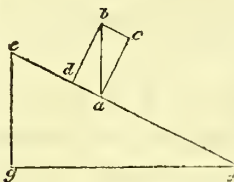


Thus again, if a ball  $b$  strike a table,  $ac$ , with velocity and direction, both represented by the line  $bc$ ; and if the ball be supposed afterwards with the same velocity to approach the table in the oblique direction  $ec$ , it will then strike with as much less force than before, as the line  $ea$  is shorter than  $ec$ . For  $ea$  is found, according to the rule for decomposing a force, given above: and, to common sense, it is obvious, that if the whole velocity

of the ball be represented by  $ec$ , the rate of approximation towards the table, or the merely downward velocity, and therefore the downward force, is marked by the line  $ea$ . The body only *falls* through the distance  $ea$  while *moving* all the way from  $e$  to  $c$ .

This last figure explains the important cases of the force of wind on ships' sails, windmill vanes, &c.; and the force of water on float-boards, water-wheels, &c.; shewing that the moving mass exerts force on a surface, not in proportion to the speed with which it may be passing along or near the surface, but to the rate of perpendicular approximation. It explains also, why the slanting blow of a club or ball is so slight, compared with the direct blow.

Another important case of the decomposition of forces is the determining with respect to a ball placed on an inclined plane, as at  $a$  upon the



plane  $ef$ , what proportion of its weight remains unsupported by the plane, and acts therefore as a force to make it roll downwards. Now if the line  $ba$  be drawn to represent the whole force or weight of the ball in the direction of gravity, we may, by the rule given in the last page, obtain the line  $bc$ , representing the tendency along the plane, and the line  $bd$  representing the pressure against the plane. But  $bc$  the tendency along will be found in every possible case, to have the same proportion to  $ba$ , the weight, as the height of the plane has to its length; for the triangular figure  $abc$ , of

which the sides are the measures of the tendency and weight of the ball, is ever perfectly similar to the other triangle  $feg$ , which has sides measuring the height and length of the plane— $b c$  corresponding to  $eg$ , and  $ba$  to  $ef$ . A body therefore on an inclined plane, seeks to roll down with force as much less than its weight as the height of the plane is less than the length. On a plane half as high as long, a ball of one pound, to prevent its rolling down, requires a force of half a pound. Horses dragging a waggon up a steep which rises one foot in ten, lift one tenth of the load besides overcoming the friction.

“ *The two great forces of Nature are ATTRACTION and REPULSION.*” (Read the Analysis.)

A person, on first approaching this subject, is far from supposing that the beautiful and almost endless variety of phenomena exhibited in the universe around, are all referrible to the two principles, *attraction* and *repulsion*, examined in the first section:—but such is the truth.—It will first be shewn here, how the great classes of accelerated, retarded, and bent motions arise from them.

*Attraction.*—Until Newton said, that what we call *weight* of bodies is merely an instance of that universal attraction of matter which diminishes with increasing distance, it was never suspected that weight was less, high up in the air than on the ground; or on a lofty mountain than on the sea-shore. But this we now know to be the case. However, in studying what goes on in obedience to gravity near the surface of the earth, except in

a few very nice cases, gravity may be considered as a uniform power ; for man has neither approached the centre of the earth in mines, nor receded from it in balloons, by more than about a thousandth part of his distance from it ; and weight has relation to the distance from the centre, not to the distance from the surface.

*“ Accelerated Motion, from Gravity.”*

Owing to the inertia of matter, any force *continuing* to act on a mass which is free to obey it, produces in the mass a quickening or accelerated motion : for as the motion given in the first instant, continues afterwards without any farther force, merely on account of the inertia, it follows, that as much more motion is added during the second instant, and as much again during the third, and so on. A falling body, therefore, under the influence of attraction, is as it were a reservoir, receiving every instant fresh velocity and momentum.

It is said that Newton’s sublime genius read the nature of attraction in the simple incident of an apple falling before him from a lofty branch in his garden.—The eye which perceives an apple beginning to fall, can follow it for a time and mark the gradual acceleration of its descent, but soon sees its path only as a shadowy line.

A boy letting a ball drop from his hand, can catch it again in the first instant, but after a little delay his hand pursues it in vain.

A fragment of rock, detached from the brow of a hill by the lightning stroke, begins its motion



slowly ; but once fairly launched, it gathers fresh speed and momentum with every instant, and bounds from steep to steep driving every obstacle before it.

Any liquid falling from a reservoir, forms a descending mass or stream, of which the bulk diminishes from above downwards, in the same proportion as the velocity of the particles increases. This truth is well exemplified in the pouring out of molasses or thick syrup : if the height of the fall be considerable, the bulky sluggish mass, which first escapes, is reduced, before it reaches the bottom, to a small thread ; but the thread is moving proportionately faster, and fills the receiving vessel with surprising rapidity. The same truth is exhibited on a vast scale in the Falls of Niagara ; where the broad river is seen first bending over the precipice a deep slow moving mass, then becoming a thinner and a thinner sheet as it descends, until at last, surrounded by its foam or mist, it flashes into the deep below, apparently with the velocity of lightning.

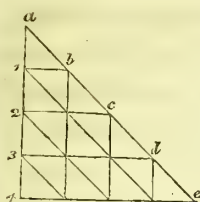
When velocity becomes considerable in any case of falling, it cannot be measured accurately by the eye, but its effects ascertain it. A man leaps from a chair with impunity, from a table with a shock, from a high window with fracture of his bones, and in falling from a balloon his body is literally dashed to pieces.

The force of gravity or general attraction is such at the surface of this earth, that, in the first second of time, it gives to a body allowed to fall a velocity of 32 feet nearly per second, that is, a



velocity which, remaining uniform from the end of the second, would carry it, without further action of gravity, through 32 feet in the next second. Yet the body falls only 16 feet in the first second; and the reason is, that the velocity of 32 feet possessed at the end of the second is gradually acquired, the body having only half of it at the half second, and as much less than half at any distance before that time, as it has more than half at the same distance afterwards; and the average, therefore, is only half of the 32, or 16 feet in the whole second. In the next second, it falls of course through the whole 32 feet, with 16 additional, from the new action of gravity, in all, three times as much as in the first second; and in two seconds, therefore, it falls altogether four times as far as in one second. At the end of two seconds the velocity is doubled, or is 64 feet per second, so that in the third second the body falls 64, and other new 16, in all, five times as much as in the first second; and in three seconds, therefore, it has descended nine times as far as in one second, &c. Knowing this progress, the velocity acquired by a falling body, and the distance through which it falls, in any given time, are easily calculated; and the height of a precipice, or the depth of a well, may be ascertained by marking the time required for a body to fall through the space.

To render sensible to the eye, and thereby to impress more strongly on the memory the relations above spoken of, the annexed figure is employed. The vertical line *a 4* marks the flux of



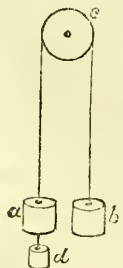
time, divided into seconds or other equal parts, 1, 2, 3, &c. ; the lines from this across to *b c d e*, mark the velocities corresponding to the ends of the times, being double for double time, triple for triple time, and so on ; the number of triangles between the horizontal lines mark how often the space described by the falling body in the first portion of time is described by it in equal subsequent portions ; and the number of triangles counted from the top of the figure to any cross line, mark how far the body has fallen at the time to which the horizontal line points. From this it will be understood, that in equal successive TIMES, there is increase in the following ways :

Of the VELOCITIES, as the simple numbers .....	}	1	2	3	4	5	&c.
Of the spaces during the several times, as the odd numbers.....		1	3	5	7	9	&c.
And of the spaces counted from the beginning of the fall, as the square numbers .....		1	4	9	16	25	&c.

It will now farther be understood that while a double force of gravity would be required to cause a double extent of fall in the same time, a quadruple force would be required to cause the same extent of fall in half the time:—and that a body descending on an inclined plane where only a part of its gravity can propel it, will have a motion as regularly accelerated as when falling freely, but a motion slower in the same proportion as the propelling force is less than the whole weight ; that is, as the height of the plane is less

than its length. With respect to bodies *rolling* down slopes, it is to be remarked that their progress is somewhat retarded by the expenditure of force in generating the rotary motion which is distinct from the progressive.

The doctrines of falling bodies are of such importance in the minute examination of many of the phenomena of nature, that much attention has been bestowed upon them. Mr. Atwood's ingenious contrivance by which the motion of falling bodies may be retarded in any desired degree, without the character of the motion being otherwise altered, has enabled experimenters to render evident to the senses all that abstract calculation had anticipated. A pound weight, left quite free, falls towards the ground, sixteen feet in the first second, proving that *attraction* of one pound is just sufficient to overcome the *inertia* of one pound at that rate. But if the inertia were doubled, or tripled, or increased in any other degree, the fall of course would be just so much slower. Now Mr. Atwood's machine in effect increases it, by causing falling weights to overcome not only their own inertia, but also that of other weights. Thus,



*a* and *b*, being weights of two pounds each, balancing each other over the very easily turned pulley *c*, are moved by a weight of one pound, *d*, hooked to one of them; and gravity in pulling this down, with force of one pound, has to overcome, not the inertia of one pound, but of five, for the other two weights must move as fast as the one pound does; and thus, the ve-

locity being reduced to one-fifth of what is natural to a falling body, the descent can be minutely observed. The experiments with Atwood's machine may be varied exceedingly, and they are most interesting.

*“ Retarded Motion,” from gravity.*

What has been said of the changing velocity of a falling body, from gravity, is exactly true, in a reversed way, respecting a rising body exposed to the same influence.

A bullet shot directly upwards, every instant loses a part of its velocity, until at last it comes to rest in the sky,—where a soaring eagle might see the messenger of death motionless and harmless for a moment by his side :—the ball then descends again, and so that, at corresponding points of the ascent and descent, but for the resistance of the air, the velocities would be equal ; and, on reaching the ground, it would have acquired exactly the velocity with which it first departed.

It is explained in a preceding paragraph, that a body falls four times as far in two seconds as in one, although the velocity at the end of two seconds is only doubled. For the same reason, a body shot upwards with double velocity, rises four times as far as if shot with a single velocity ; if shot with triple velocity, it rises nine times as far, and so forth.

In aiming for amusement at bodies thrown up into the air, it is easy to hit them near their point of turning, and more difficult always as they are nearer to the ground, whether rising or falling.



An upward jet of water is small below, where it issues from the pipe with great velocity, but it becomes more bulky as the water loses velocity in ascending, and at the top, it often spreads a little like a palm tree, and any light round solid will continue supported and playing upon its summit.

The rise of a pendulum from the bottom of its arc, is an exact copy, reversed, of its previous descent to that point.

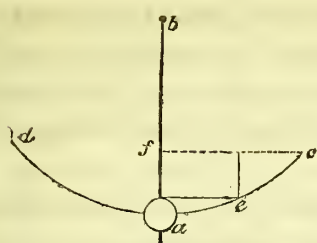
“ *The Pendulum* ”

exemplifies well both accelerated and retarded motion. The name is applicable to any body so suspended that it may swing freely backwards and forwards. When such a body is made of certain form and length, although so simple, it is one of the most admirable contrivances of man's ingenuity.

Galileo having observed the hanging chandeliers of lofty ceilings to continue vibrating long and with singular uniformity, after any accidental cause of disturbance, was led to investigate the laws of the phenomenon ; and out of what, in some shape or other, had been before men's eyes, but uselessly, from the beginning of the world, his powerful genius extracted the most important results. Independently of the light which the theory of the pendulum has thrown on various branches of physics, the instrument itself, with a few wheels attached, to record its vibrations, has now become the perfect time-keeper, regulating many of the affairs of men.

A common pendulum consists of a ball, as





*a* suspended by a rod from a fixed point as *b*, and made to swing backwards and forwards, or to vibrate, under this point. Being raised to *c*, and then set at liberty, it falls back

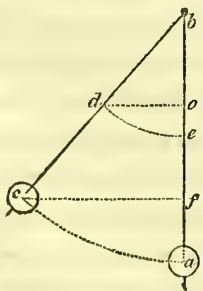
to *a* with an accelerating motion like a ball rolling down a slope, and when arrived there, it has just acquired momentum enough to carry it to *d*, at an equal elevation on the other side; from this it falls back again, again to rise, and would so go on for ever, but for the impediments of air and friction.—The pendulum is strictly an object of mathematical study; but we shall give a general idea of its important characteristics in common language.

1. The *times of the vibrations* of a pendulum are very nearly equal, whether it be moving much or little, that is to say, whether the arc described by it be large or small. This remarkable property is what makes it a time-keeper. The reason that a large vibration is performed in the same time as a small one, in other words, that the pendulum always moves faster in proportion as its journey is longer—is, that in proportion as the arc described is more extended, the steeper are its beginning and ending, and the more rapidly, therefore, the pendulum falls down at first, sweeps along the intermediate space, and stops at last. It is evident, for instance, that the portion *c e* of the arc (p. 96) is much more steep than the equal portion *e a*.—A pendulum made to vibrate in the curve called a

*cycloid*, which, in the central part, very nearly coincides with a circular arc, but towards the extremities rises a little more steeply, has its beats perfectly *isochronous*, or in equal times, whatever their extent.

A common clock is merely a pendulum, with wheel-work attached to it, to record the number of the vibrations, and with a weight or spring having force enough to counteract the retarding effects of friction and the resistance of the air. The wheels shew how many swings or beats of the pendulum have taken place, because at every beat, a tooth of the last wheel is allowed to pass. Now if this wheel has sixty teeth, as is common, it will just turn round once for sixty beats of the pendulum, or seconds, and a hand fixed on its axis projecting through the dial-plate, will be the second hand of the clock. The other wheels are so connected with this first, and the numbers of teeth on them so proportioned, that one turns sixty times slower than the first, to fit its axis to carry a minute hand, and another by moving twelve times slower still, is fitted to carry an hour hand.

2. The *length of a pendulum* influences the time of its vibration.—Long pendulums vibrate more slowly than short ones, because, in corresponding arcs or paths, the bob or ball of the long pendulum has a greater journey to perform, without having a steeper line of descent. If a pendulum  $b a$  be twice as long as another reaching from  $b$  to  $e$ , it has twice



as much to fall in its descending arc  $ca$ , as the other in its arc  $de$ , while in corresponding parts of the two paths, the slope or inclination is always equal:—the ball of the long pendulum may be considered as having rolled twice as far down a given slope as the ball of the short pendulum. Now as a body falls four times as far, either directly or on any uniform slope, in two seconds as in one (see page 91), a pendulum must be four times as long, to beat once in two seconds, as to beat every second. A pendulum of a little more than 39 inches beats seconds; one of four times that length is required to beat double seconds, and one of one-fourth the length to beat half seconds.—As a pendulum to answer its purpose must be of invariable length, one which beats seconds constitutes an easily found standard of measure.

Because the smallest change in the length of a pendulum alters the rate of going of the clock, it is important to be able to counteract the dilatation or contraction of pendulums caused by the changing heat of the seasons; and for this purpose various ingenious means have been contrived. One of the best of these is the *gridiron pendulum*, as it is called, from consisting of various rods of metal. It renders the different dilatibility by heat of two metals composing it, the cause of unchanged length in the whole. The adjoining sketch may shew that if the central rod of brass represented by the *strong* line from  $b$  to  $c$ , dilate alone just as much as the two rods of steel, represented by the *weaker* lines on either side of



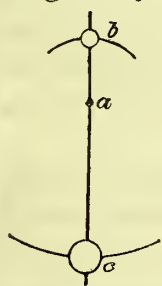
the other, dilate together (the expansion of brass by heat is about double that of steel), it will exactly counteract the lengthening of these, and will keep the ball *d* always at the same distance from the point of suspension *a*. Some astronomical clocks in the present day are so perfect, that they do not err one beat of the pendulum in a year. Common clocks are regulated by a screw which lifts or lets down the ball of the pendulum, and so changes the effective length, that is the distance between the point of suspension and what is called the *centre of oscillation*, treated of in the next chapter.

3. The *force* of gravity, of course, is what determines how long the pendulum shall be in falling to the bottom of its arc, and how long in rising, for the ball of the pendulum, as already stated, may be considered as a body descending by its weight on a slope; a change in the force of gravity, therefore, would at once alter the rate of all the clocks on earth. At the equator of our earth, where the gravity of bodies is counteracted in a small degree by the centrifugal force arising from the earth's motion (as explained at *page 74*), a pendulum vibrates more slowly than elsewhere, and must therefore be made shorter to answer the same purpose. Corresponding results take place when a pendulum is carried to a mountain top, and therefore farther away from the centre of the earth, which is the centre of attraction—or when carried to the bottom of a mine, where it is attracted by the matter above it, as well as by the matter beneath.



The popular prejudice refuted at page 76, that a large or heavy body should fall to the earth, even in a vacuum, more quickly than a small or light body, attaches itself also to the case of a heavy and a light pendulum. Now there is no difference for pendulums of the same length, whatever their weight or material, but what depends on the resistance of the air. It is a very remarkable fact thus proved, that in all substances the gravity and inertia perfectly agree.

There is a small pendulum called a *metronome*, used by musicians for marking time; which, although very short, may still be made to beat whole seconds, or even longer intervals. The reason of its slow motion is, that its rod is prolonged beyond its axis of support, at *a*, upwards,



to *b*, and has a ball upon the top, at *b*, as well as on the bottom, at *c*; which upper ball prevents the under one from moving so fast as it otherwise would, just as a small weight attached to one end of a weighing-beam, prevents a greater weight attached to the other end

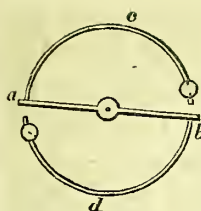
from falling so fast as it would if there were no counterpoise. The rate of motion changes with any change in the distance of the ball *b* from the centre of motion *a*; and to allow of such change, the ball *b* is made to slide.

A pocket-watch differs from a clock, in having a vibrating wheel instead of a vibrating pendulum; and as, in a clock, gravity is always pulling the pendulum down to the bottom of its arc, which



is its natural place of rest, but does not fix it there, because the momentum acquired during its fall from one side is just sufficient to carry it up to an equal height on the other—so in a watch, a spring, generally spiral, surrounding the axis of the balance-wheel, is always forcing this towards a middle position of rest, but does not fix it there, because the momentum acquired during its approach from either side to the middle position, carries it just as far past on the other side, and the spring has to begin its work again. The balance-wheel at each vibration allows one tooth of the adjoining wheel to pass, as the pendulum does in a clock, and the record of the beats is preserved by the wheels which follow, as already explained for the clock. A main-spring is used to keep up the motion of a watch, instead of the weight used in a clock; and as a spring acts equally whatever be its position, a watch keeps time although carried in the pocket, or in a moving ship.

As the rate of a clock is influenced by the length of its pendulum, so is the rate of a watch by the size or diameter of its balance-wheel; and heat which retards the motion of a common clock by lengthening the pendulum, retards the motion of a common watch by dilating the balance-wheel. Ingenuity however has found a remedy for the latter case as for the former, *viz.* the contrivance called the *expansion balance-wheel*. Of this the circumference, instead of being a continuous ring, is made up of two half-rings, as *c* and *d*, each attached by one end only, *viz.* *c* at *a*, and *d* at *b*, to a cross bar *a b*, and which half rings being



composed of brass on the convex side, and of steel on the concave, bend or curl inwards by heat—as a sheet of damp paper bends when held to the fire—and thus for the time diminish the size of the wheel at their free extremities, so as just to counterbalance its increase at the fixed extremities by the expansion or lengthening of the cross bar.

As the motion of a pendulum has relation to the *force of gravity*, so has the motion of the balance-wheel to the *stiffness of the balance-spring*; and the regulator of a watch is merely a pin which bears against the balance-spring, and by sliding backwards or forwards, so as to shorten or lengthen the part of the spring left free to act, changes the degree of its stiffness. A change produced by the variation of temperature is compensated for by the expansion-wheel described above.

It would be exceeding the limit marked out for this general work, to speak more particularly here of those admirable watches which have been produced within the last thirty years under the name of *chronometers*, for the purpose of ascertaining the longitude at sea; but the author may perhaps be excused for mentioning a moment of surprise and delight which he experienced, on first seeing their singular perfection actually proved. After months spent in a passage from South America to Asia, his pocket chronometer with others on board, announced one morning that a certain point of land was then bearing east from the ship at a distance of fifty miles; and in an hour afterwards,

when a mist had cleared away, the looker-out on the mast gave the joyous call of “Land a-head!” verifying the report of the chronometers almost to a mile, after a voyage of thousands. It is natural at such a moment, with the dangers and uncertainties of ancient navigation before the mind, to exult in contemplating what man has now achieved. Had the rate of the wonderful little instrument in all that time been changed even a little, its announcement would have been worse than useless,—but in the night and in the day, in storm and in calm, in heat and in cold, while the persons around it were experiencing every vicissitude of mental and bodily condition, its steady beat went on, keeping exact account of the rolling of the earth and of the stars; and in the midst of the trackless waves it was always ready to tell its magic tale of the very spot of the globe over which it had arrived. The mode of using a chronometer for so valuable a purpose will be explained in the section on astronomy.

*Bent or curvilinear motion from attraction.*—This takes place whenever attraction is acting across the path of any existing free motion. The flying cannon-ball or stone, drawn down by gravity, is an example, for the projectile force ceases with the first impulse, but the bending force is acting every instant, and by every instant producing a new effect causes a curvilinear path.

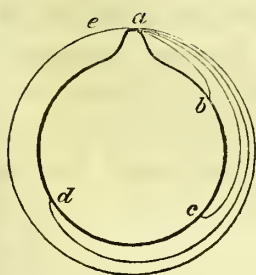
An oblique jet of water is to the eye a permanent exhibition of the curve described by a body thus projected. The particles of the liquid move in the line which they would describe if projected

singly, and the continued succession of them marks the line of situations through which each passes in its course to the earth.

A cannon or musket ball, shot quite horizontally over a level plain, will touch the ground or plain just as soon as another ball dropt at the same instant directly from the cannon's mouth; for the forward or projectile motion does not, in such a case, at all interfere with the action of gravity. This result, which most persons, before consideration, would be disposed to doubt, makes strikingly sensible the extraordinary speed of the cannon-ball; *viz.* that it has already moved perhaps six hundred feet forward, during the half second that a ball dropt from the hand of a standing person requires to reach the earth only four feet beneath. The fact also explains why, for a long range, the gun must be pointed more or less upwards.

A dozen marbles swept horizontally from off a table by a stick, all reach the floor at the same instant, how different soever the distances to which they may respectively be driven.

The particular study of the subject of projectiles is very important to military engineers; and we know how successfully they have pursued it, by the precision with which they now direct their shot and shells to objects at very great distances.



(1.)

A cannon-ball shot horizontally from the top of a lofty mountain, would go three or four miles. (The mountain is here represented on an enlarged scale, as standing on the globe *b, c, d*, at *a*.) If



there were no atmosphere to resist its motion, or if the mountain top were above the surface of the atmosphere, the same original velocity would carry it thirty or forty miles before it fell, as to *b*: with more force still, it would reach to *c*, and with still more to *d*. And if it could be despatched with about ten times the velocity of a common cannon-shot, it would not have approached nearer to the earth than at first, even when it had again reached round to *e* or to *a*; and its velocity being undiminished, it would perform a second similar tour, and then a third, and so forth: it would, in fact, have become a little satellite, or planetary body, revolving round the earth. In the successive ranges represented in the figure, it is seen that the centrifugal force of the ball, or its tendency to move in a straight line, becomes more and more nearly a counterbalance to gravity, and at last is exactly equal to it. If the force given to the ball were more than sufficient to bring it round again to the level of *a*, it would for a time fly off, or increase its distance from the earth, acquiring somewhat of the eccentric motion of a comet. There may really be such revolving masses above our atmosphere, although invisible to us, owing to their smallness. It has been supposed by some, that the meteoric stones, which fall to the earth every now and then, come from such bodies, or are the entire masses, having become entangled in our atmosphere, so as to lose their forward velocity. The four little planets discovered lately beyond the orbit of Mars, are not larger than a six-thousandth part of our earth.



REPULSION,—produces *accelerated*, *retarded*, and *bent* motions, like attraction, but it acts only at minute distances, while *attraction* draws from the sun, or from the very limits of the universe: *repulsion* acts, for instance, between the adjoining atoms of an elastic fluid. Yet repulsion plays a part in the economy of nature, not at all inferior to its sister attraction. We have already seen, when considering the constitution of masses in *section first*, that repulsion prevents or modifies the contact of the atoms of all bodies; that with increase of temperature, it causes these atoms to separate, and of a solid forms a liquid, or even an air; that it operates around all masses as if it were a film or covering, preventing their mutual cohesion, &c. &c.

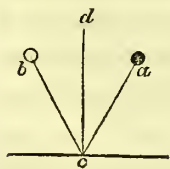
*Accelerated* motion from repulsion, is seen when the atoms of gunpowder explode and propel the bullet from the bottom of a piece to the muzzle with such rapidly increasing velocity. The strength of this repulsion of gunpowder is so much greater than the strength of gravity or common attraction, that its action on a bullet, during the passage along a barrel of five or six feet in length, may not be overcome by gravity, during an ascent of a mile or more.

A visibly *retarded* motion from repulsion, is exemplified by a moving body coming against a spring or a bladder full of air, or against the piston-handle of an air-syringe, so as to compress the air beneath it.

Any elastic body striking against another body and recoiling, exhibits in conjunction the pheno-

mena of retardation, acceleration, and often also of bending, chiefly from repulsion ; for instance :

An ivory ball driven forcibly against a marble slab, does not stop at the instant that apparent contact takes place, but still advances and compresses that part of the substance which is against the marble,—as is proved by the facts mentioned at page 42. While this compression of the ivory is going on, the resistance made by the increasing repulsion of the particles gradually retards, and ultimately destroys the forward motion of the ball; and at the instant of its final arrest, the parts in contact, both of the ball and of the marble, being in their greatest degree of compression, act on the ball, and repel it again with gradually accelerating motion, until it leaves the marble, with the same velocity which it had on approaching. The retardation and acceleration take place here within so small a space, and in so short a time, that they are not apparent to sense, but the mind perceives the nature of the phenomenon as distinctly as if the ball had rolled against the end of a long steel spring.—If the ball strike the marble obliquely, as from *a* to *c*, in a path forming the angle *a c d* with a perpendicular line, it does not rebound in the same line by which it approached, but just as obliquely towards the other side, *viz.* from *c* to *b*; and it then exhibits a bent motion from repulsion. This case illustrates also the “resolution of motions,” for the oblique descent *a c* being composed of a direct downward motion from *a* to the table, and a horizontal or forward motion



from *a* towards the perpendicular, the table destroys the downward motion and converts it into an opposite directly upward motion, but it does not affect the forward motion, which immediately combines again with the upward, and carries the ball as far beyond the perpendicular at *b* as it was distant from it at *a*. The important law in physics, of which this case is an example, is usually expressed—"The angles of incidence and of reflection are equal." It applies to all reflected bodies, as balls, waves, sound, light, &c.

If the ivory ball and marble, in the above case, were supposed to be both perfectly hard, and without elasticity, still the repulsion which surrounds all bodies, as a thin covering, preventing their cohesion (see page 30), would act exactly as the real elasticity of the ivory, and would cause a retarded motion until perfect rest came, and then an accelerated motion back again, until the ball recovered its primitive velocity.

Collision between hard bodies always exhibits more or less of the truth now described: when it occurs between soft bodies, as lumps of lead or of moist clay, the approaching parts mutually displace each other, and there is no recoil.

When a straight steel plate, of which the end is fixed in a block, is bent, as by a ball rolling against it, the particles on the side which becomes concave are made to approximate, and there is a resistance or repulsion gradually increasing among them; the particles on the convex side, again, are drawn a little more from each other, and are therefore exerting attraction to return: the recoil of the

spring is thus owing to both forces trying to replace the particles in their former relative situations.

“ *Tides, Winds, &c. exemplify Attraction.*” (Read the Analysis, page 49.)

Until we reflect attentively on this subject, we are far from perceiving that all the phenomena of nature are only instances of *attraction* and *repulsion*, acting under variety of circumstances.

ATTRACTION.—*Tides* are raised by the attraction of the moon and sun, and fall again by the general attraction of the earth : producing in many of the shallower parts of the ocean very rapid horizontal currents. They do a great deal of work for man. They carry his ships along the coasts, and up and down the rivers ; they turn water-wheels for him ; they fill his docks and canals at convenient times ; they rise to receive his ships, launched from elevated building yards, &c. What a busy scene is a great sea-port river, during the rising and falling of the tide—with the thousands of people along its banks, borrowing assistance in their various occupations !

*Winds* are produced chiefly by the fluid atmosphere seeking its level, in obedience to the attraction of the earth, after the action of disturbing causes, such as the heat of the sun, &c. They help man in the important business of *navigation* ; they turn his windmills, &c.

*The Currents* of rivers, are water constantly descending on slopes, that is, regaining its level, in obedience to the earth's attraction. Water-



mills and inland navigation are among the advantages which they afford to man.

*All falling and pressing bodies* exhibit attraction in its simplest form.

REPULSION—is instanced in *explosion, steam*, the action of *springs, &c.*

*Explosion* of gunpowder is repulsion among the particles when assuming the form of air.

*Steam*, by the repulsion among its particles, moves the piston of the steam-engine. In our days it performs half the labour of society.

Accidental explosions of fire-damp, or hydrogen in mines, and the tremendous evolutions of elastic fluid in volcanoes and earthquakes, are other instances of the same class.

*Elasticity*, as seen in springs, collision, &c. belongs chiefly to repulsion; as seen in India-rubber, and other substances resuming their usual length after extension, it belongs chiefly to attraction.

A spring is often, as it were, a reservoir of force, kept ready charged for a purpose; as when a gun-lock is cocked, a watch wound up, &c.

It will be remarked, with respect to many of the phenomena now and hereafter to be mentioned, that it is not the original Attraction or Repulsion which man uses as his servant, but the momentum gradually accumulated in masses by the exertion of such attraction or repulsion; in other words, the *inertia* is used as a great working power or force.

*Electrical, galvanic, magnetical, and optical* phenomena, are also in great part peculiar attractions and repulsions, as will be seen in the chapters



devoted to the explanation of them. And even the *actions of animals*, so infinitely varied, are all results of a shortening of the fleshy threads called muscular fibres, which is produced by the mutual *attraction* of their component particles ;—just as the varied motions of a telegraph, or of a ship's yards, are produced by the shortening of certain ropes of connexion.

However closely allied the last-mentioned particular attractions and repulsions may be to the general attraction and repulsion formerly treated of, it is found convenient to consider them apart.

In the remarkable phenomena of nature and art, all the motions being caused, as now shewn, by Attraction and Repulsion, these forces do not operate by a single impulse, but through a repetition of impulses, or a continued action, of which the effect is gradually accumulated in the inertia of matter. Thus all great velocities and momenta are the terminations of an accelerated motion.

Meteoric stones, falling from great heights, bury themselves deep in the earth by the force of their gradually acquired velocity.

When the wood-cutters among the Alps launch an enormous tree from high on the mountain side, along the smooth wooden trough or channel prepared for it, and in fewer minutes than it traverses miles, it is seen plunging into the lake below ; it acquires its frightful velocity, not at once, but through the action of gravity continued during the whole of its descent.

The shock or blow of the ram of a pile-engine, is not the effect of momentary attraction between it and the earth, but of that attraction accumulating motal inertia or power, during the descent of the ram through a space of twenty or thirty feet.

A common hammer, in its instantaneous shock, has the condensed effect of the arm and of gravity, as accumulated through its whole previous course ; and when a powerful blow is intended, the hammer, or hatchet, or club, or fist in boxing, is lifted high, or carried far back, that there may be time and space for imparting greater power.

The inferior animals, by many of their actions, illustrate the same truth, and prove their experimental or instinctive acquaintance with it.

Sea birds carry shell-fish up into the air, and drop them on smooth stones to break them, and to obtain the food. It is related in Grecian story, that a bird once mistook the venerable bald head of a sage meditating on the sea-shore for a smooth stone, and by the same act killed an oyster and the philosopher.

There are some long-necked birds, that fight and kill their prey by a blow of their beak. They draw back the head, bending the neck like a swan or serpent, and then dart it forward, with a continued effort, until the strong wedge-like beak reaches its destination, almost with the velocity of a pistol bullet. One snake in darting its fangs at another passing swiftly across its coil, has been known to miss its aim and inflict a mortal wound on its own flesh.

Bulls, rams, and goats, in fighting, alternately recede and run at each other, that the shock may be great when their foreheads meet.

A horse in kicking, from the great length of his leg, and the consequent space through which he can be adding velocity to his foot, drives it at last against the object almost like a cannon shot.

A bow-string propelling an arrow, follows it through a considerable space, and so gives the great velocity at last produced.

A sling gives to the hand the power of adding velocity to the stone through a long path; for the hand moves in a small circle while the stone moves in a larger, and the hand being kept always somewhat in advance of the stone, pulls at it without intermission, until the moment of discharge.

The battering rams of the ancients allowed those about them to accumulate in them the efforts of many hands, and of a considerable duration of action, so as to give at last one great and sudden shock.

Even the gentle action of the human breath, exerted for a time on a pea or small hard ball of clay while passing through a long smooth tube, gives a velocity which will inflict a sharp and painful stroke on a distant animal. In Borneo and others of the Eastern Islands, poisoned arrows are thrown in this way with great force and precision.

The action of gunpowder on bullets, although appearing so sudden, is still not an instantaneous, but a gradual, and therefore accelerating action; and accordingly we find the effect to depend much on the length of the piece along which the force

pursues the ball. A small fast-sailing vessel with a single long gun, has often compelled a very superior vessel, whose guns were shorter, to yield.

For the same reason that all great velocities require continued action or repeated impulse to produce them, so do they also to destroy them; the inertia of motion and of rest being exactly equal.

A vast mass of rock suspended like a pendulum, and allowed to sweep down its curve from a considerable elevation, would arrive at the bottom like a battering ram, with force sufficient to shake a thick wall or rampart to its foundation. The continued action of gravity would have given this force, and if, instead of the solid resistance supposed, and which would scarcely be sufficient to take the whole momentum away, the mass were merely allowed to continue its course as a pendulum, and to ascend on the other side, the continued action of gravity then opposing its motion, would bring it to powerless rest again, by the time when it had reached an elevation equal to that from which it fell.

Soft air expanding gives gradually the death-carrying velocity to the cannon ball; and soft air, or cotton, or wool, resisting in a close strong tube, —if the bullet could be directed exactly into it— would again gradually annihilate the motion. Were the attempt made, however, to stop the ball suddenly, by a block of the hardest granite, the block would instantly be riven by its force.

Bales of cotton or thick masses of cork, attached round a ship, will receive cannon balls, and bring



them to rest, without themselves suffering much, while the naked firmer side of the ship would be penetrated. The cotton or cork offers an increasing resistance through a considerable space, while the oak opposes its hard front at once, and must instantly suffice or be destroyed. A hard body, that it may at once destroy such a motion as we are supposing, must be able to oppose as much force in perhaps the space of one hundredth of an inch, that is, in the extent to which its elasticity will let it yield without breaking, as the moving cause gave, through a much greater space (a plate of steel will thus oppose a pistol-bullet); and when it cannot do this, it must be broken or penetrated by the moving body. It is to be remarked, however, that the continued opposition of a thick mass of wood, stone, or earth, to an entered bullet, brings it to rest at last as any elastic unbroken opposition would. Gunners have ascertained the exact depth in each substance to which a ball will penetrate; and they call buildings *bomb-proof* or *ball-proof*, which have a thickness or depth exceeding that.

A hempen or silken rope supporting the scale of a weighing beam, would resist a greater weight *falling* into the scale than would be resisted by an iron chain which were even stronger than the rope for the purpose of bearing a *quiescent* weight: because the hemp or silk would yield by its elasticity, and continue its resistance through a considerable space and time, and thus would at last gradually overcome the momentum; while the iron, by scarcely yielding at all, would require to



be strong enough to stop the mass suddenly, or would break.

Yet for the same reason that iron is weakest in such a case as the last, it is stronger than hemp or rope when used as a cable for a ship, to withstand the sudden force of waves. This will be understood on considering, that the chain by its weight hangs as a curve or inverted arch in the water, while the rope being nearly of the weight of water, is supported in it almost as a straight line from the anchor to the ship; therefore, when a great wave dashes against the ship, the bent chain will yield until it be drawn nearly straight, by which great extent of yielding, and consequent length of resistance, it will withstand a great shock; whereas the straight rope, as it can yield only by the elasticity of its material, and comparatively, therefore, a little way, will resist much less.

A heavy ship moving quickly with the tide or wind, could not be stopped instantly by a short rope or chain of any magnitude: if the attempt were made to destroy at once so vast a momentum, something would certainly give way; but a rope of very moderate size, kept tight between the shore and the ship, and from time to time allowed to slip a little round a wooden block, when the tightness threatened its breaking, would accomplish the end very soon and easily.

The following are further proofs that forces are to be measured as much by the time or space through which they act, as by their difference of intensity or momentary power.

A door standing open, and which would yield readily on its hinges to the gentle push of a finger, is not moved by a cannon ball piercing through it. Now the ball really overcomes the whole force of cohesion among the atoms of tough wood : but that force is allowed to act or resist for so short a time, owing to the rapid passage of the ball, that it is not sufficient to affect the inertia of the door, in a degree to produce sensible motion. The cohesion of the circle in the door, cut out by the ball, would have borne a weight of more than a hundred pounds laid quietly upon it, but supposing the bullet to fly twelve hundred feet in a second, and the door to be one inch thick, the cohesion being allowed to act for only the 14,400th part of a second, its influence is not perceived. The following are other examples of the same kind.

A leaden bullet pressed slowly against a pane of glass, breaks it irregularly, where the strength happens to be least ; but the same bullet shot at it from a pistol, makes only a small round hole. It has been amusingly said of such a case, that the particles struck and carried away, have not time to warn their neighbours of what is happening.

A cannon-ball, having very great velocity, passes through a ship's side, and leaves but a little mark ; while one with less speed splinters and breaks the wood to a considerable distance around. A near shot thus often injures a ship less than one from a greater distance.

A sheet of paper standing edgeways on a

table, is not driven down by a pistol-ball fired through it.

The truth at present under consideration explains, with respect to gun-shot wounds, why the man often remains ignorant for a time of his misfortune, and why a rapid bullet only kills the parts which it touches, while a spent-ball may bruise and injure all around. In many cases of injury, popularly attributed to the *wind of a ball*, the ball itself has really touched the part.

A man lying down and receiving the blow of a great hammer on his chest, would be killed by it; but if a heavy anvil be first laid upon the chest, and the blow be then received upon the anvil, the man bears it with impunity. Here the quantity of motion in the hammer, being diffused through the great mass of the anvil, produces but a trifling velocity, which the elasticity of the chest, in its slow yielding, easily overcomes.

A circular plate of soft iron, made to turn with extreme rapidity, will cut through the hardest steel file, almost as a knife cuts through a carrot. In cases where a soft powder suffices to polish a hard body, it acts partly like this plate, by the motion or velocity given to the wearing particles.

*“There is no motion or action in the universe, without a concomitant and opposite action of equal amount.”* (See the Analysis.)

This truth has otherwise been expressed—“action and reaction are equal and contrary.”—It is evident, that if no action or movement takes place on earth but in consequence of either At-

traction or Repulsion,—and this has now been shewn—there must always be two objects or masses concerned, and each must be *attracted* or *repelled* just as much as the other, although one will have less velocity than the other, as it may be itself greater, or fixed to another mass.

If a man in one boat pull at a rope attached to another, the two boats will approach. If they be of equal size and load, they will both move at the same rate, in whichever of the boats the man may be; and if there be a difference in the sizes, and resistances, there will be a corresponding difference in the velocities, the smaller boat moving the fastest.

A magnet and a piece of iron attract each other equally, whatever disproportion there is between the masses. If either be balanced in a scale, and the other be then brought within a certain distance beneath it, the very same counterpoise will be required to prevent their approach, whichever be in the scale. If the two were hanging near each other as pendulums, they would approach and meet; but the little one would perform more of the journey in proportion to its littleness.

A man in a boat pulling a rope attached to a large ship, seems only to move the boat: but he really moves the ship a little, for, supposing the resistance of the ship to be just a thousand times greater than that of the boat, a thousand men in a thousand boats, pulling simultaneously in the same manner, would make the ship meet them half way.

A pound of lead and the earth attract each



other with equal force, but that force makes the lead approach sixteen feet in a second towards the earth, while the contrary motion of the earth is of course as much less than this as the earth is weightier than one pound,—and is therefore unnoticed. Speaking strictly, it is true, that even a feather falling lifts the earth towards it, and that a man jumping kicks the earth away.

A spring unbending between two equal bodies, throws them off with equal velocity; if between bodies of different magnitudes, the velocity of the smaller body is greater in proportion to its smallness.

On firing a cannon, the gun recoils with even more motion or momentum in it than the ball has, for it suffers the reaction of the expelled gunpowder as well as of the ball; but the momentum in the gun being diffused through a greater mass, the velocity is small, and easily checked.

The recoil of a light fowling-piece will hurt the shoulder, if the piece be not held close to it.

A ship in chase, by firing her bow guns, retards her motion; by firing from her stern she quickens it.

A ship firing a broadside, heels or inclines to the opposite side.

A vessel of water suspended by a cord hangs perpendicularly: but if a hole be opened in one side, so as to allow the water to jet out there, the vessel will be pushed to the other side by the reaction of the jet, and will so remain while it flows. If the hole be oblique, the vessel will constantly turn round.



A vessel of water placed upon a floating piece of plank, and allowed to throw out a jet, as in the last case, moves the plank in the opposite direction.

A steam-boat may be driven by making the engine pump or squirt water from the stern, instead of making it, as usual, move paddle-wheels. There is a loss of power however in this mode of applying it, as will be explained under the head of "Hydraulics."

A man floating in a small boat, and blowing strongly with a bellows towards the stern, pushes himself onwards with the same force with which the air issues from the bellows pipe.

A sky-rocket ascends, because, after it is lighted, the lower part is always producing a large quantity of aeriform fluid, which, in expanding, presses not only on the air below, but also on the rocket above, and thus lifts it. The ascent is aided also by the recoil of the rocket from the part of its substance, which is constantly bursting downwards.

He was a foolish man who thought he had found the means of commanding always a fair wind for his pleasure-boat, by erecting an immense bellows in the stern. The bellows and sails acted against each other, and there was no motion: indeed, in a perfect calm, there would be a little backward motion, because the sail would not catch all the wind from the bellows.

A man supported on a floating plank, by walking towards one end of it gives it a motion in the direction opposite.

A man using an oar, or a steam-engine turning paddle-wheels, advances exactly with the force that drives the water astern.

A swimmer pressing the water downwards and backwards with his hands, is sent forwards and upwards with the same force, by the reaction of the water.

And a bird flying, is upheld with exactly the force with which it strikes the air in the opposite direction.

A man pushing against the ground with a stick, may be considered as compressing a spring between the earth and the end of his stick, which spring is therefore pushing him up as much as he pushes down ; and if, at the time, he were balanced in the scale of a weighing beam, he would find that he weighed just as much less as he were pressing with his stick.

Thus an invalid, on a spring plank or chair, who by a trifling downward pressure of his hand on a staff or on a table, causes his body to rise and fall through a great range, and thus obtains the advantage of almost passive exercise, is really lifting himself while he presses downward.

When a boy cries, on knocking his head against a table or pane of glass, he is commonly told, and truly, that he has given as hard a blow as he has received ; although his philosophy probably, looking chiefly to results, blames the table for his head hurt, and his head for the glass broken.

The difference of momentum acquired in a fall of one foot or of several, is well known : the corresponding intensities of reaction are unpleasantly

experienced by a man who sits down in an easy chair, or who, in sitting down where he supposed a chair to be, unexpectedly reaches the floor.

What motion the wind has given to a ship, it has itself lost, that is to say, the ship has re-acted on the moving air: as is seen when one vessel is becalmed under the lee of another.

When one billiard ball strikes directly another ball of equal size, it stops, and the second ball proceeds with the whole velocity which the first had—the action which imparts the new motion being equal to the reaction which destroys the old. Although the transference of motion, in such a case, seems to be instantaneous, the change is really progressive, and as follows. The approaching ball, at a certain point of time, has just given half of its motion to the other equal ball, and if both were of soft clay, they would then proceed together with half the original velocity; but, as they are elastic, the touching parts at the moment supposed are compressed like a spring between the balls, and by then expanding, and exerting force equally both ways, they double the velocity of the foremost ball, and destroy altogether the motion of that behind.

If a billiard-ball be propelled against the nearest one of a row of balls equal to itself, it comes to rest as in the last case described, while the farthest ball of the row darts off with its velocity,—the intermediate balls having each received and transmitted the motion in a twinkling, without appearing themselves to move.

As further illustrative of the truths, that action

and re-action are equal and contrary, and that in every case of hard bodies striking each other, they may be regarded as compressing a very small strong spring between them, we may mention, that when any elastic body, as a billiard-ball, strikes another body larger than itself, and rebounds, it gives to that other, not only all the motion which it originally possessed, this being done at the moment when it comes to rest, but an additional quantity, equal to that with which it recoils—owing to the equal action in both directions of the repulsion or spring which causes the recoil. When the difference of size between the bodies is very great, the returning velocity of the smaller is nearly as great as its advancing motion was, and thus it gives a momentum to the body struck, nearly double of what it originally itself possessed. This phenomenon constitutes the paradoxical case of an effect being greater than its cause, and has led persons, imperfectly acquainted with the subject, to seek from the principle, a *perpetuum mobile*. A hammer on rebounding from an anvil has given a blow of nearly double the force which it had itself, for the anvil felt its full original force while stopping it, and then, equally with itself, was affected by the repulsion which caused its return.

Many other interesting facts might be adduced as examples of equal action and reaction, but these will suffice.

This second section of the work has now explained the nature of INERTIA in matter, and has shewn that the infinitely varied phenomena of

motion, which the universe exhibits, are only *attraction* and *repulsion*, acting on the *inertia* of *atoms* separate or conjoined, under diversified circumstances.—And such is the sublime simplicity of the whole scheme of nature.



## PART II.

## PHENOMENA OF SOLIDS.

THE FOUR FUNDAMENTAL TRUTHS USED TO EXPLAIN THE PECULIARITIES OF STATE AND MOTION WHICH DEPEND ON THE *SOLID* FORM OF BODIES: A DEPARTMENT COMMONLY CALLED *MECHANICS*.

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## ANALYSIS OF THE CHAPTER.\*

*A force, which moves part of a solid body, must affect the whole or break off the part.*

*If the force be directed towards a certain central point in the mass, it will affect the whole equally, whether simply to support the mass, or to move it, or to stop it when in motion. The point, according to circumstances, is called the CENTRE OF GRAVITY, OF INERTIA, or OF ACTION.*

*In solid bodies moving about an axis, as exemplified in a wheel or weighing beam, the various parts describe circles or move through spaces, which are greater in proportion to their respective distances from the centre of motion. Hence forces differing as to speed, may still, through a solid medium, be brought exactly to co-operate or to oppose one-another; a slow force counterbalancing or being equivalent to a quicker one, provided that it be more intense in proportion as it is slower. The SIMPLE MACHINES, or MECHANICAL MEDIA, called LEVER, WHEEL AND AXLE, PULLEY, INCLINED PLANE, WEDGE, SCREW, &c. are so many arrangements of solid parts, by which forces of different velocities and intensities may be thus connected or opposed, or may be conveniently substituted one for another.*

*By solid connecting parts also the direction of any existing motion or force may be changed, as when the straight motion of running water is converted into the rotatory motion of a water-wheel, &c. Hence arises an endless variety of COMPLEX MACHINES.*

\* The reader should here re-peruse the general table or synopsis at page 1.

*In all machines, an important circumstance to be considered is the resistance among moving parts which arises from FRICTION :— and in solid structures generally, the forms and positions of parts have to be adjusted to the STRENGTH OF THE MATERIALS, and to the strains which the parts have to bear.*

“ *Solid* ” is the term applied to a mass in which the mutual attraction of the atoms is so strong, that the mass may be moved about as one body, without the relative positions of the component parts being thereby disturbed.

*“ Force moving part of a solid must affect the whole or break off the part.”*

This is a necessary consequence of the description or definition of a solid just given. And it follows that in all cases of breaking, the cohesion of the atoms at the fractured part must have been less strong than—the weight of the remaining mass, or its inertia resisting the degree of change attempted, or the force fixing it to its place, or than some combination of these particulars.

The sharp blow of a hammer given to an ivory ball, causes it to dart off swiftly, but does not injure it, because the cohesion among the atoms struck, is stronger than the opposing inertia of the mass, even under a rapid change : but the blow of the hammer on a large elephant’s tusk, indents or breaks the part, because the opposing inertia of the larger mass is stronger than the cohesion of the atoms which receive the blow.

A vessel of pottery-ware may be safely suspended by its handle ; proving that the cohesion which fixes the handle to it is stronger than the

weight of the vessel ; but if the attempt be made to lift the vessel quickly, the handle may rise and leave the body behind ; because then the weight and inertia are acting together to destroy the cohesion. Thus servants attempting to lift too quickly the loaded stone-ware dishes at a dinner-table, often break off the part by which they take hold.

“ *Centre of Gravity or Inertia.*”

If any uniform beam or rod be supported by its middle, like a weighing beam, the two ends will just balance each other. This is in accordance with the general truth or law of *attraction* already explained ; for as there is just as much similarly situated matter on one side of the support as on the other, there will also be just as much attraction, and therefore no reason why the matter on one side should overpower that on the other. If equal weights be afterwards attached in corresponding situations on the two arms of the beam, the balance will not be thereby disturbed ; and the operation of adding weights that counterpoise, above and below, and near and far from the centre, may be continued, until a bulky mass is built up upon the beam—and instead of a beam a wheel may be used—yet the whole will remain perfectly supported and in equilibrium about the original centre. In the pages now to follow, it will be shewn that, in every body or mass, or system of connected masses, in the universe, there is a point of this kind about which all the parts balance or have equilibrium, and it is this point

which is called the *centre of gravity* or of *inertia*. Although in any mass, therefore, every atom has its separate gravity and inertia, and the weight and inertia of the whole are really diffused through the whole, still by supporting this one point, either from above or from below, the whole mass is equally supported; by lifting it, the whole is lifted; by stopping it, the whole is brought to rest; and when it rises or falls, the general mass is really rising or falling. Thus for many purposes a body, however large, may be considered as compressed into or existing only in the single point called its *centre of gravity* or of *inertia*.

This centre in a mass of regular shape and of uniform substance, as a ball or cube of metal, is easily found, because it is the evident centre of the form; but in bodies that are irregular, either as to density or form, it must be found by rules of calculation, hereafter explained.

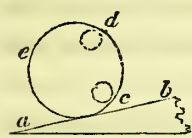
To say that the centre of gravity will always take the lowest situation which the support of the body will allow, is only to repeat, that bodies tend by their gravity towards the centre of the earth. In a suspended body, therefore, as the lowest situation which the centre of gravity can find is, when it is immediately under the point of suspension, all bodies hanging freely must have their centre of gravity directly under that point. A plummet is an interesting example of this; and the truth furnishes in many cases of irregular masses, a very simple practical mode of finding the centre.



Thus if an irregular piece of plank or of paste-board, represented here by the figure *a e b d*, be suspended from any point, as *a*, and the cord of a plummet *a g* be attached at the same point, the centre of gravity of the board must be somewhere in the direction of the plummet, and a chalk line left on the board where the cord touched it, must pass over the centre of gravity. If the board be then suspended by another point, as *d*, and another chalk line *d e* be made in the same manner, the place *c*, where the two lines cross or cut each other, will indicate the centre of gravity; and the board, when supported by a cord attached there, will hang evenly balanced.

The following cases farther illustrate the truth, that the centre of gravity always seeks the lowest place. They seem at first to be exceptions to the law; but when more fully considered, are interesting proofs of it.

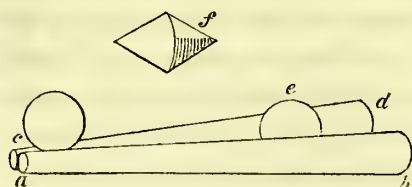
A wooden cylinder or roller *e d c*, placed on a slope or inclined plane *a b*, will naturally descend, because, its centre of gravity is thereby approaching the earth; but if there be a heavy mass of lead *c* introduced at one side, which must rise before the roller can descend, the rise of the mass being contrary to gravity, the motion will be arrested. Indeed, if the roller were placed on the plane with the lead in the position *d*, the lead would fall down to the position *c*, and so would move the roller towards *b*, exhibiting the singular





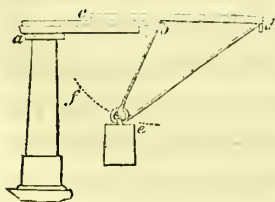
phenomenon of a body rolling up hill by the action of its weight.

If a billiard-ball be placed upon the small ends



of two billiard sticks or cues *a b* and *c d*, laid on a table with their points *c* and *a* in contact, but with the larger

ends *b* and *d* so far apart that there may be just room for the ball to touch the table between them, the ball will roll along between the cues, sinking gradually from its high situation near their points, to its slower situation near *b*. To a careless observer, it would then have the appearance of rolling upwards, because the cues on which it rests are thicker towards the ends *d* and *b*; but it would really be descending in obedience to gravity. If a double cone, as represented at *f*, were substituted for the ball, it would similarly roll from *c* to *e*, and with still more of the fallacious appearance of rolling upwards, because its ends would always be resting on the upper and rising surfaces of the cues.



The board or stick *c d* resting on the edge of the table *a b* would naturally fall if left to itself, because more than half of it is beyond the edge of the table; but strange to

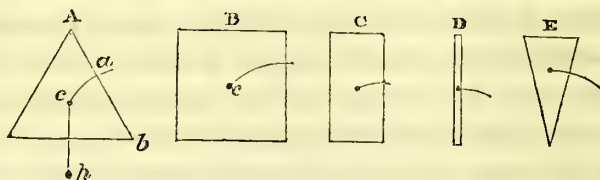
say, an additional weight *e* attached to its projecting part as at *b* by the cord *b e*, instead of pulling it down faster, shall fix or steady it on the table,

provided the weight be pushed inwards a little by a rod  $d e$  resting against it and against a niche in the stick at  $d$ . It is evident that the stick  $c d$ , in falling, must turn round the edge of the table at  $b$ ; but in so doing, after the arrangement now supposed, it must lift the weight  $e$  along the path  $e f$ —which rise, as the weight is heavier than the stick (that is to say, as the common centre of gravity of the connected objects is near  $e$ ), gravity forbids, and therefore the stick and weight will both remain supported by the table. An umbrella or walking cane, hanging on the edge of a table by a crooked handle, is another instance of the same kind. And the common toy of a little man standing on tiptoe upon the top of a pillar, and supporting two leaden bullets by wires descending from his hands, is another combination of parts which places the centre of gravity of the whole below the support, making the combination a kind of pendulum.

By attending to the centre of gravity of the bodies around us on earth, we are enabled to explain why, from the influence of gravity, some of them are stable or firmly fixed, others tottering, others falling.

If we find that a body, from its form or position, cannot be overturned without its centre of gravity being lifted,—knowing now that the general mass is then lifted in the same degree, we see why a weak cause cannot effect the change. The rise of the centre of gravity, or body, in any case of falling over, where the centre of gravity is over the middle of the sustaining base, will be propor-

tioned to the breadth of the base of the body, compared with the height of the centre of gravity above the base. This is shewn in the annexed figures, in which the two particulars of *base* and *height* are combined in a series of proportions.



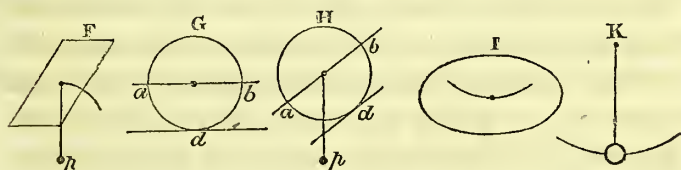
In the figures the dot *c* marks the place of the centre of gravity, and the curved line beginning from the dot marks the path of the centre of gravity, when the body is overturned. This curved line is a portion of a circle which has the edge or extremity of the base (*b*, in fig. A) as a centre, because the body in turning must rest upon such extremity or corner as the centre of its motion. The farther inwards, therefore, from this extremity that the centre of gravity is, as marked by where a plumb line as *p*, hanging from it, crosses the base, the farther of course is the centre of gravity from the top of the circle which it has to describe in moving, and the steeper, consequently, will be its commencing path; and as in the case of bodies made to roll up slopes, the steeper the ascent, the greater will be the force necessary to give motion.—The line of a plummet hanging from the centre of gravity is called the *line of direction* of the centre, or that in which it tends naturally to descend to the earth.

In fig. A, which has a broad base and little height of the centre of gravity, we see that the

centre must rise almost perpendicularly before it can fall over, and the resistance to overturning is therefore nearly equal to the whole weight of the body. Hence the firmness of a pyramid.

In figures B, C and D, progressively, the commencing path of the centre is less and less steep, because the base is narrower, and hence the bodies are so much the less stable. B may represent an ordinary house, C a tall narrow house, and D a lofty chimney.

Fig. E shews a tottering position, for the centre of gravity being directly over a base which is a mere point, the least inclination places it on a descending slope, and the body must fall.



In F the position is tottering on one side, and stable on the other. This explains how the least inclination of a standing body virtually narrows, in one direction, its sustaining base.

In G, which represents a ball upon a level plane, the whole mass is supported on a single point as in E, yet the body has no tendency to move, because in any other possible position the centre would still be as far from the sustaining plane. In moving, the centre describes the straight level line *a b*.

In H the ball is on an inclined plane, and rolls down, the centre of gravity describing the oblique line *b a*.



In I, which is an oval body resting on a level plane, when the body is moved to either side, the centre of gravity must rise, as in the case of a pendulum. Hence an oval body on a level will rock or vibrate like a pendulum.

K is a true pendulum whose centre of gravity describes the curve here shewn; as explained in the first chapter, at page 95.

The importance of the subject of the centre of gravity will be farther judged of by the facts which are now to be reviewed.

A cart loaded with metal or stone may go safely along a road of which one side is higher than the other, as here shewn, but were the same cart loaded with wool or hay it would be overturned; because, although the sustaining base be the same in the two cases, the *line of direction* falls much within it from the low centre of gravity of the metal at *c*, but falls very near the wheel at *p*, or altogether on the outside, from the high centre of the wool at *a*, and in the latter case the centre has offered to it a descending path.



This explains why lofty stage coaches or vans are so dangerous, and particularly when heavy luggage is placed on the top, and why lofty gigs and curricles have led to so many fatal accidents. As regards any of these, a defect of smoothness or of level in the road, or even, in a case of quick driving, a slight lateral bend, often suffices to produce the catastrophe. The safety coaches of late



times are made with the wheels far apart to give a broad base, and with the luggage-receptacles and seats for outside passengers placed low down before and behind the body of the carriage, instead of on the top as formerly.

The feet of tripods are generally expanded below to give a broad base. The same is true of our common chairs; but a thoughtless child often leans so far over the back of a chair, that he causes the line of the general centre of gravity to fall beyond the base, and the chair with its load is overturned. The small lofty chairs made to raise children to the parent's elbow at the dinner-table, are very dangerous if the feet are not made to spread much. Pillar-and-claw tables, candlesticks, table-lamps, and many other articles of household furniture, have stability given in the same manner.

The least inclination of a standing body virtually narrows the supporting base.

This truth is explained by *fig. F.* It shews the necessity of building the thin walls and tall chimneys of modern houses perfectly upright. And hence the extreme importance and utility of that simple instrument the *plummet* or *plumb-line*, which when applied to a body, is a visible indication of the line of its centre of gravity. The mason and many other workmen cannot proceed a step without their guiding plummet.

The brick walls of ordinary houses are so thin, that, to have standing strength, they require to rest against one-another; and hence they occasionally exhibit the kind of stability which belongs to

a child's house built of cards. As contrasted with the masses of masonry which remain to us from antiquity, resting on firm-spreading basements, they are examples of what is truly ephemeral, in comparison with that which has partaken of the permanency of nature's own works, covering regions with mighty ruins. What magnificent illustrations of strength and durability dependent on proportions, are those ancient pyramids and temples, which still give such interest to the banks of the Nile, and to the valleys and plains of Asia!

There are many remarkable structures on earth which lean or incline a little: yet so long as the line of their centre of gravity remains within the base, and the parts of the mass have tenacity among themselves sufficient to hold together, the structure will stand. The famous tower of Pisa was built intentionally inclining, to frighten and surprise: with a height of one hundred and thirty feet, it overhangs its base sixteen feet, and assumes nearly the air of fig. F, in page 133.

The tall monument near London Bridge inclines so much, that in high winds from a particular quarter, timid minds have doubted of its stability.

And many of the most lofty and beautiful of our cathedral spires or towers, as that of Salisbury, have lost something of their perpendicularity.

An oval body on a flat level surface, as already explained by fig. I, page 133, oscillates somewhat like a pendulum, because when disturbed from its middle position, its centre of gravity has risen and seeks to return. The same is true of any regular

slice or portion of a solid globe, which will consequently always come to rest with its plane face turned directly upwards.

The rocking-horse of children and the common cradle are exemplifications of the same class.

But perhaps the most curious instances are those rocks called Loggan or Laggan stones, of which there are several among the picturesque barriers of the British coast. An immense mass, loosened in some convulsion of nature, is found with a slightly rounded base resting on a flatter surface of rock below ; and is so nearly balanced, that the force of a man suffices to move it. Some of these have been objects of much superstitious veneration to their neighbourhood.

There is an amusing Chinese toy, made in obedience to the same principle. It has the appearance of a little fat laughing man, sitting on the ground with his feet concealed under him ; but where the feet should be, there is only a rounded smooth surface, with heavy lead ballast placed in it, so low, as always, when allowed, to raise the body to the erect or sitting attitude. A child pushes the little fellow down again and again, and would persuade him to be still, but is surprised to see him always up the moment after, shaking about and as lively as ever.

The vibratory motion of a pendulum, as dependent upon the circumstance of the centre of gravity having been moved from its lowest place which it again constantly seeks, was so fully considered in the last chapter, that it need not be

again dwelt upon here ; but we have to enumerate the following phenomena as being of the same class.

—The vibrations of a common swing.

—The rocking of a balloon when it first ascends.

—The spontaneous shutting of those gates or doors of which the upper hinge overhangs or projects beyond the lower, causing the gate when in the shut position to have its lock lower than when in any other. Such a gate always returns of itself, from either side, to the shut position, just as a pendulum returns to the lowest part of its arc :—the gate in fact is but a sloping pendulum.

Of the same nature also is the rocking or rolling of a ship, in particular states of the wind and sea. When the centre of gravity of a ship is too low, owing to all the heavy load being placed near the keel, this pendulum-motion, in rough weather, becomes excessive and dangerous.

The actions and postures of animals, and particularly of man, illustrate beautifully the observations made above with respect to the centre of gravity.

A body, we have seen, is tottering in proportion as it has great altitude and narrow base—but it is the noble prerogative of man to be able to support his towering figure with great firmness, on a very narrow base, and under constant change of attitude. This faculty is acquired slowly because of the difficulty. A child does well who walks at the end of ten or twelve months ; while the young of quadrupeds, which have a broad sup-



porting base, are able to stand and even to move about almost immediately after birth.

The supporting base of a man is the space occupied by and included between the feet. The advantage of turning out the toes is, that without taking much from the length of the base, it adds considerably to the breadth.

If there be much art in walking on two perfect feet, there is still more in walking on two slender wooden legs, with rounded extremities :—which, however, we often see done, by mutilated soldiers and sailors.

All the ladies of the empire of China have to acquire nearly the same talent as these victims of war ; for barbarous custom has crippled them, by confining their feet for life, in such shoes as fitted them in infancy.

But surpassing in difficulty any of these instances is the practice, which is general among the inhabitants of the sandy plains called the *Landes*, in the south-west of France, of walking on stilts. The *Landes* afford tolerable pasturage for sheep ; but during one portion of the year are half covered with water, and during the remainder are still very unfit walking-ground, by reason of their deep loose sand and thick furze. The natives meet the inconveniences of all seasons by doubling the length of their natural legs, through the addition to them of the stilts mentioned, which they call *des échasses*. Mounted on these, which are wooden poles, put on and off as regularly as the other parts of dress, they appear to strangers a new and extraordinary race of long-legged beings,



marching over the loose sand, or through the water, with steps of eight or ten feet in length, and with the speed of a trotting horse ; their moderate journeys being of thirty or forty miles in a day. While watching their flocks, they fix themselves in convenient stations, by means of a third staff which supports them behind, and then with their rough sheep-skin cloaks and caps, like thatched roofs over them, they appear like little watch-towers, or singular lofty tripods, scattered over the face of the country.

Still beyond the art of walking on stilts is that which some persons attain of walking and dancing on a single rope or wire ; or even of keeping the centre of gravity above the base, while standing on the moveable support of a galloping horse. —A rope-dancer usually carries a long pole in his hand, to balance him : it is loaded at each end, and when he inclines, he throws it a little towards the side required, that the reaction may restore his perpendicularity.

Much art of the same sort is shewn in the attitudes and evolutions of the skaiter ; in the amusements of supporting a stick upright on the end of the finger ; and in many other feats of a like kind.

*Attitudes* generally depend on the necessity of keeping the centre of gravity of the body over the base under variety of circumstances, as in—the strait or upright port of a man who carries a load on his head ;—the leaning forward of one who carries it on his back ;—the hanging backwards of one who bears it between his arms ;—the leaning to one

side of him who is carrying a weight on the other side;—the habitual carriage of very fat people, whose head and shoulders are thrown back, giving a certain air of self-satisfaction,—an air which belongs also to the expectant mother, and even to the dropsical patient, although producing in the latter so sad an incongruity.

When a man walks or runs, he inclines forward, that the centre of gravity may overhang the base: and he must then be constantly advancing his feet to prevent his falling. He makes his body incline just enough to produce the velocity which he desires.

A man, in pulling horizontally at a load, is merely causing his body to overhang its base, so that its tendency to fall may become a force or power applicable to the work.

When a man rises from a chair, he is seen first to bend the body forward, or to draw the feet backward, so as to bring the feet or base under the centre of gravity, and then he lifts the body up. If he lift too soon, that is, before the body be sufficiently advanced, he falls back again.

A man standing with his heels close to a perpendicular wall, cannot, without falling, bend forward sufficiently to pick up any object that lies before him on the ground; because the wall prevents him from throwing part of his body backward, to counterbalance the head and arms which must project forward. A person little versed in such matters, might agree to give ten guineas for permission to possess himself, if he could, of a purse of twenty, laid on the ground before him: he of course would lose his stake.

When a man walks at a moderate rate, his centre of gravity comes alternately over the right and over the left foot. This is the reason why the body advances in a waving line, and why persons walking arm in arm shake each other, unless they make the movements of their feet to correspond, as soldiers do in marching.

*Sea sickness* is a subject closely related to the present. Man requiring, as now explained, so strictly to maintain his perpendicularity, that is, to keep the centre of gravity always over the supporting part of his body, ascertains the required position in various ways, but chiefly by comparing the perpendicularity, or other known position of things about him, with his own position. Vertigo, and sickness, are the consequences of depriving him of his standards of comparison, or of disturbing them.

Hence on shipboard, where the lines of the masts, windows, furniture, &c. are constantly changing, sickness, vertigo, and other affections of the same class, are common to persons unaccustomed to ships. Many persons experience similar effects in carriages, and in swings; or on looking from a lofty precipice, where known objects being distant, and viewed under a new aspect, are not so readily recognized; also in walking on a wall or roof; in looking directly up to a roof, or to the stars in the zenith, because then all standards disappear; on entering a round room, where there are no perpendicular lines of light and shade, as when the walls and roof are covered with a paper

which has no regular arrangement of spot ; on turning round, as in waltzing, or if placed on a wheel ; because the eye is not then allowed to rest long enough on any standard, &c.

People when in the dark, and therefore blind people always, use standards belonging to the sense of touch ; and it is because, on board of ship, the standards both of sight and of touch are lost, that the effect is so very remarkable.

But sea sickness also partly depends on the irregular pressure of the bowels among themselves and against the containing parts, when the influence of their inertia and weight varies with the rising and falling of the ship.

From the nature of sea sickness, as discovered in these facts, it is seen why persons unaccustomed to the motion of a ship, often find relief by keeping their eyes directed to the fixed shore, where visible ; or by lying down on their backs and shutting their eyes ; or by taking such a dose of exhilarating drink as shall diminish their sensibility to all objects of external sense.

As no condition or form of matter escapes from the great laws of nature, we find the attitudes and general condition of vegetable as well as of animal bodies, characterized by the necessity of having the centre of gravity supported over the base. With what admiration may we contemplate the pine and other trees in the forests of nature, springing up to heaven as perpendicularly as if the plummet had been at work to direct them ; and no less on the brows of precipitous hills than in the level plains. On a smaller scale, we see



the grasses and corn-stalks of our fields, illustrating the same truth. And whenever, in tree or shrub, accident or peculiar nature causes a deviation from perpendicularity, additional strength and support are provided.

*Beauty of form or position* is often felt to exist in bodies, merely because they possess the shape and support required, that the centre of gravity may be stable.

In architecture, how displeasing is a wall or pillar that is not quite upright ; or a column with too small a base ; or a very tall narrow house ; or a long slender chimney. On the other hand, how beautiful in a lofty edifice is the suitable succession of columns, from the massive Doric of the basement, supporting the whole superstructure, to the light Corinthian or kindred forms seen above. The Chinese pagoda is a fine example of the union of certain requisites for stability, *viz.* perpendicularity and expanding base, with the other qualities of perfect symmetry, graceful proportion, and fanciful ornament. When seen crowning a rising ground in a wooded island, or springing up from the centre of a rich garden, it forms, perhaps, one of the most beautiful objects which fancy has ever designed.

*Beauty of attitude and grace of carriage* in the human individual, are in great part referable to the same principle.

The postures of opera dancers might pass as intentional illustrations of the number of ways in



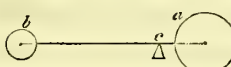
which the centre of gravity may be kept above a narrow base, by counteracting one disturbing motion or extention of a limb by some opposite and corresponding motion. The common statue of the god Mercury on tiptoe is a permanent familiar illustration of such a beautifully balanced attitude.

Grace of carriage includes not only a perfect freedom of motion, but also a firmness of step, or steady bearing of the centre of gravity over the base. It is usually possessed by those who live in the country, taking much and varied exercise, or who make gymnastics a part of their discipline. What a contrast is there between the gait of the active mountaineer, enjoying the consciousness of perfect nature, and that of the mechanic or shop-keeper, whose confinement to the cell of his trade, soon produces in his body a shape and air corresponding to it:—and in the softer sex what a difference is there, between that active and graceful fair one who recalls to us the fabled Diana of old, and that other sedentary being, who having scarcely trodden but on smooth pavements or carpets, under any new circumstances, carries her person as if it were a load quite new and foreign to her.

The *centre of gravity*, is also the *centre of inertia*. When a person lifts a uniform rod by its middle, the inertia of both ends being equal, he overcomes it equally, and raises them evenly together. When he lifts by a part nearer to one end, the shorter and lighter portion having less inertia will rise the first, and there will be a turning motion of the

rod round the finger as a centre, proportioned to the excess of inertia in the greater side.

The *centre of gravity*, or *inertia*, however, is not necessarily in the centre of the mass;—for if



a weight of three pounds, *a*, be affixed to one end of a rod, and a weight of only one pound, *b*, be affixed to the other, the two will still be balanced, if supported or lifted by a point of the rod, *c*, three times nearer to the centre of the large weight than to the centre of the small one. This fact is explained under the head of *lever*, a few pages hence. For the sake of simplicity, in describing such experiments, the weight of the connecting rod itself is neglected.

The *centre of gravity* or *inertia* is also the *centre of centrifugal force*:—for if the balls *a* and *b* of the last figure were made to spin round a common centre, as by making the connecting rod rest and turn upon a point or pivot at *c*; unless the point *c* were the centre of inertia of the two, the pivot would always be drawn in the direction of that end of the rod at which there were the greatest centrifugal force. It is on this account that in the case of a millstone, or great fly-wheel, or of the balance-wheel of a watch, the axis must pass through the centre of inertia, to prevent its being more worn on one side than on the other.

When we say, in astronomy, that the earth revolves round the sun, or that the moon revolves round the earth, we do not speak with absolute correctness, for in all such cases, both bodies are revolving round the common centre of inertia of

the two. In the case of the sun and earth, as the former is about a million times larger than the latter, the common centre of inertia of the two is a million times nearer to its centre than to the centre of the earth, and is therefore within its body or circumference.

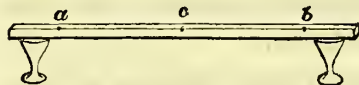
The *centre of inertia* in a body moving evenly, is also its *centre of action* or *percussion*; because, if such centre come against an obstacle, the whole momentum of the body acts there and is destroyed; while, if any other part than the centre hit, the body loses only a part of its momentum, and revolves round the obstacle as a pivot or centre of motion, to pass it on the side towards which the greater inertia happened to be.

In a hammer, or a bar of iron used as a hammer, or in a pendulum, the motion is not said to be *even*, because the velocity of the different parts is different, being greatest far from the hand or centre of motion, and the centre of all the motal inertia is nearer to the fast moving end than to the other. Its exact place, in many cases, is easily ascertained by calculation. In a uniform rod moving as a pendulum, for instance, it is at the distance of one-third from the lower end. In the pendulum it is called the *centre of oscillation*.

If a man use a bar or rod of iron as a hammer, he must take care to make it strike the object by its centre of action, or his own hand will receive a part of the shock. A very heavy mass thus carelessly used will seriously strain the wrist. In a common hammer, as the chief part of the matter is at the end, the centre of percussion is there too,

and no precaution of the kind mentioned is required.

If a rod or small log of wood be suspended horizontally by a string tied to its middle, or be floating in water, and if a forward blow be given directly across it near to one end, the other end will be found, in the first instant, to have moved a little backward, or in a direction contrary to the blow, as if the rod had been fixed upon an axis. The inertia of the general mass, by resisting the motion, becomes in effect a fixed axis. This truth is amusingly illustrated by laying the ends of a long stick on two wine-glasses, and then breaking the stick by a smart downward blow of a poker on its centre.



Instead of breaking the glasses also, as by such a blow, might be expected, the ends of the stick rise at the instant of the stroke, to turn round certain *centres of resistance* in the fragments, as at *a* and *b*, and then fall harmless on the table.

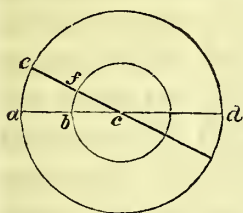
In this *section* we have seen what admirable simplicity is given to many of our reasonings and operations, by considering bodies in reference only to their *centre of inertia*, under one or other of its names.

“ *In a solid body moving about an axis, like a wheel or weighing-beam, the different parts have different velocities, according to their respective distances from the axis or centre.*” (Read the Analysis.)

The truth of this proposition is perceived at



once on comparing the motion in the rim of a wheel, or near the ends of a weighing-beam, with that in parts nearer the centres. Suppose  $a$



$d$  to be a line drawn across a wheel, or along a weighing-beam, the centre of motion in either case being at  $c$ ; then the outer circular line or path  $ac$ , which a point at  $a$  describes

when moving, is longer than the corresponding inner line,  $b f$ , which a point at  $b$  describes in the same time, as  $a$  is farther from the centre than  $b$ . This admits of easy mathematical demonstration, and is indeed merely an instance of the truth, that the proportions existing between any parts or lines in one circle, hold with respect to the corresponding parts and lines in all circles.

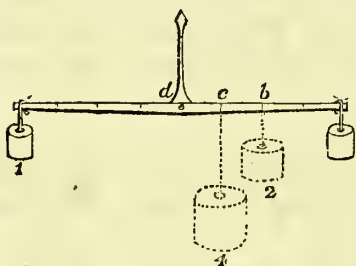
*“Hence forces with different speed may still be placed in continued connexion or opposition; and they will balance or be equivalent, if the one be as much more intense than the other as it is slower.”*  
(Read the Analysis.)

This is the important truth upon which the whole of mechanics may be said to hinge. It gives to man the *simple machines* or *mechanical powers*, as they have been called,—the Lever, Wedge, Pulley, &c., which enable him to adapt any species and speed of power which he can command, to almost any work which he has to accomplish: and the discovery of it and of means to apply it may be said to have subjected external nature to his control. His works are of a thousand kinds,



from the displacing of a rock to the spinning of a delicate thread ; while the natural powers or forces at his command are chiefly wind, waterfalls, fire, and animal effort—and of which in any particular case he may have only one kind at his service ;—still, being able to connect together his power and resistance by solid media, of which different parts move with any desired difference of velocities, he can employ any force, for a purpose of almost any kind.

There is, however, a false and most pernicious prejudice very generally existing with respect to the *simple machines*, which we must begin by removing, *viz.* that they increase the quantity of power or force applied to them. For instance, when one pound, as *a*, at the end of a beam or lever, is seen balancing two pounds, at *b*, at half the distance on the other side of the axis, or four pounds, as *c*, at a quarter of the distance ; many

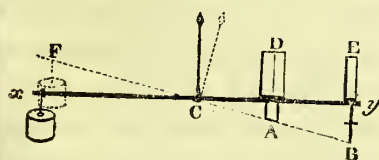


persons believe that the lever itself gives or begets a force equal to the difference of the weights so balanced. But we shall now shew, that levers and all the other *mechanical powers*

(as from the erroneous idea above mentioned they have been called), merely enable us to make such substitutions, as that of a small weight descending far, in place of a greater weight descending a little way, or of an inferior force working long, instead of a superior force working for a shorter time,—

and thus often to accomplish ends to which the force possessed would be quite unsuited if applied directly. In other words, the simple machines enable us to concentrate or divide any kind or quantity of force which we possess, so as to suit it to our various purposes, just as mill-ponds and branching channels enable us to accumulate or divide the force of a stream of water; but they no more increase the *quantity of power* than a mill-pond increases the quantity of water. When any slender force is caused, through a machine, to produce some effect which seems proportioned to an intense force, it has always to act longer, or through more space than the other, just in proportion as it is more slender; as a small stream of water acting for ten minutes, may produce the same effect as a greater gush in one minute. Twenty feet of the action of a small horse near the circumference of a great wheel, may be rendered, by intervening machinery, equivalent to ten feet of the action of a heavy ox or elephant nearer the centre. And one horse in drawing through six hundred feet, or a hundred horses in drawing through six feet, or the piston of a great steam-engine, in rising once from the bottom to the top of its cylinder, &c., may all be made to do the same work.

To illustrate this subject farther; we shall sup-



pose a weighing-beam  $xy$ , with a weight of one pound hanging at the end  $x$ ; then if a spring issuing from

(1.)

L

the fixed box at E, with uniform force of one pound, be made to push at the other end of the beam  $y$ , it will just balance the weight; and if it be in the slightest degree stronger than the weight, it will push the end of the beam  $y$  down to B, and will raise the weight to F. If, instead of the single spring of one pound at the end of the beam, two such springs be applied at half-way from the centre to the end, so as to press at A, where there is just half the extent of motion, or room to act, as at B, exactly the same effect will follow. Now because one spring at the end of the beam, is seen here doing the same work as two similar springs, or a single spring of double strength at the middle, it might at first appear that there were a saving of power by using the single spring and longer lever; but let it be observed, that the two middle springs have each issued from their box only one inch, while the single spring at the end has issued two inches: in both cases, therefore, exactly two inches of one-pound spring have been used.

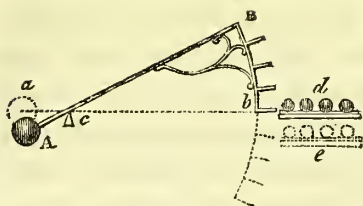
In the last experiment, pound weights or little buckets of water might be used instead of the springs, and with exactly the same result—one pound or pint at the end of the arm producing the same effect as two pounds or pints at the middle of it: but it would be observed that the single quantity fell two inches, while the double quantity at half distance fell only one inch; and to replace them after they had done their work, there would evidently be the same labour, whether a person had to lift the single quantity first one inch, and

then another, or had to lift, first, one half of the double equipoise an inch, and then the other half as much.—Each atom of matter may be considered as held to the earth by its thread of attraction, and if one atom rise or fall ten inches, just as much of the supposed thread of attraction will be drawn out or returned as if ten atoms rise or fall one inch. And so, where a weight of one pound is made to do any work, instead of a weight of two pounds, there is no more saving than in giving away two yards of single rope instead of one yard of double rope; and in like manner for all other differences of intensity.

If a man were to exert a force of one hundred pounds at A, in the above figure, to lift the weight, a boy at B, with force of fifty pounds, might do the same work; but the man would only have worked or pressed down through one foot, while the boy would have worked through two; and therefore, although the boy with the assistance of the lever, seemed to become as strong as the man, the case would merely be, again, that of the one-pound spring unbending two inches, to produce an effect equal to that of the two-pound spring unbending one inch. The boy would be using two feet of his smaller force, where the man used one foot of his greater force; and if the work had to be long continued, the boy would have completely exhausted himself when the man remained yet fresh.

A case of the lever, exhibited in this diagram, serves well to explain the nature of *mechanical powers* in general. Suppose A to be a weight of four pounds at the end of a rod or lever AB, made





to turn on *c* as an axis or fulcrum, and having the arm *c B* four times as long as the arm *c A*, (but the two arms of the lever being equi-

poised so as not to conceal the action of weights subsequently attached to them); then one pound at the end *B*, would balance the four pounds at the end of *A*, and with the slightest additional weight would preponderate. Now let us suppose the arc *B b* to have been fixed to the long arm of the lever with the four projections or shelves here shewn, on which balls of one pound might rest; then if one of the four balls from the plane *d* were to roll upon the first shelf, it would just balance *A*, and, with one grain more, would descend to the plane *e*, one inch below; then a second ball of one pound would occupy the second shelf, and would descend in the same way, to be followed by a third, and afterwards by a fourth; and when the whole four had fallen from *d* to *e*, they would just have lifted the four-pound mass, at the other end of the lever, one inch. So that, although one pound were seen here lifting four pounds, it would only have lifted them one-fourth part as far as it fell itself, and the sum of the phenomenon would be, that four pounds, by falling one inch at the long end of the lever, had raised four pounds through the same distance of one inch at the short end. No *mechanical power* or *machine* generates force more than the lever does in this case.

It appears, then, from all this, that as the *quan-*



*tity of motion* in a body is measured by its velocity and the number of atoms in it conjointly, so the *quantity of force* exerted in any case, is measured by the *intensity* of the force conjointly with the *space* through which it moves. A clear mode, therefore, of comparing forces, is to state the *lengths* and the *intensities*—for instance, to speak of ten feet of one-pound force, as equal to one foot of ten-pound force, &c.

A horse pulling with the force of fifty pounds goes generally at the rate of six miles an hour ; the steam-engine piston is generally made to move at the rate of two hundred feet per minute, bearing a pressure of steam of about twenty pounds to each square inch of its surface ; a particular mill-stream may have a force of one hundred pounds, with a velocity of a hundred and fifty feet per minute :—now it is easy, by simple arithmetic, and the rule of *length* and *intensity* above explained, to compare all these and other forces as applicable to any given work. We must warn the reader, however, that there are many important considerations connected with the practical employment of forces, according to their respective nature and that of the resistance to be overcome, which cannot be entered upon in this elementary work. In very many cases there is a great waste or unavoidable loss of force, because the resistance, in yielding, runs away or escapes from the force ; as when a ship runs away from the wind which is driving her, or the floats of a quick moving water-wheel, from the stream which turns it. Horses drawing boats or carriages at the rate of five miles an hour, might

exert great force, but to have a speed exceeding twelve miles they might require their whole effort to move their own bodies. As a general rule, although *equal quantities* of force balance each other when applied to parts of a lever or wheel altogether or nearly at rest, still when a force is made to act near an axis or fulcrum, to produce considerable velocity in a more distant part of the machinery, much of it is wasted in pressure against the fixed fulcrum.

What an infinity of vain schemes—yet some of them displaying great ingenuity—for perpetual motion, and new mechanical engines of power, &c. would have been checked at once, had the great truth been generally understood, that no form or combination of machinery ever did or ever can increase, in the slightest degree, the quantity of power applied. Ignorance of this is the hinge on which most of the dreams of mechanical projectors have turned. No year passes, even now, in which many patents are not taken out for such supposed discoveries; and the deluded individuals, after selling perhaps even their household necessities to obtain the means of securing the expected advantages, often sink in despair, when their attempts, instead of bringing riches and happiness to their families, end in disappointment and ruin. The frequency, and eagerness, and obstinacy, with which even talented individuals, owing to their imperfect knowledge of this part of natural philosophy, have engaged in such undertakings, is a remarkable phenomenon in human nature. Examples of such schemes will be noticed

in different parts of this work, where they may serve to illustrate points under consideration.

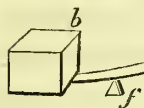
“ *Lever, wheel and axle, &c.*” (Read the Analysis, at page 125.)

These are the simplest of the contrivances, which the circumstance of solidity in masses has enabled man to adopt, for the purpose of connecting or opposing forces and resistances of different intensities. We proceed to describe them, and to explain some of their useful applications.

“ *Lever.*”

A beam or rod of any kind, resting at one part on a prop or axis, which becomes its centre of motion, is a lever; and it has been so called, probably, because such a contrivance was first employed for lifting weights.

This figure represents a lever employed to move a block of stone: *a* is the end to which the *power* or *force* is applied, *f* is the *prop* or *fulcrum*, and the mass *b*



is the *weight* or *resistance*. According to the rule already given and explained at page 144, the power may be as much less intense than the resistance, as it is farther from the fulcrum, or moving through a greater space. A man at *a*, therefore, twice as far from the prop as the centre of gravity of the stone *b*, will be able to lift a stone twice as heavy as himself; but he will lift it only one inch for every two inches that he descends: and two men would be required, acting at half the distance, to do the same work.

There is no limit to the difference, as to intensity, of forces which may be made to balance each other by the lever, except the length and strength of the material of which levers have to be formed. Archimedes said, "give me a lever long enough, and a prop strong enough, and with my own weight I will lift the world." But he would have required to move with the velocity of a cannon-ball for millions of years, to alter the position of the earth by a small part of an inch. As stated in a former part of the volume, this feat of Archimedes is, in mathematical truth, performed by every man who leaps from the ground: he kicks the world away from him when he rises, and attracts it again when he falls back.

To calculate the effect of a lever, in practice, we must always take into account the weight of the lever itself, and the fact of its bending more or less; but in expounding the theory of the lever, it is usual to consider first, what would be the result, if the lever were a rod without weight and without flexibility.

The rule for the lever, that the opposing forces, to balance each other, must be more or less intense, exactly as they act nearer to or farther from the centre, holds in all cases, whether the forces be on different sides of the prop or both on the same side, and whether the force nearest to the prop have the office of power or of resistance; it holds also, whether the lever be straight or crooked.

The following are examples of levers with the prop between the forces.



The *handspike*, represented in page 157, is a lever moving a block of stone. The same form when made of iron, with the extremity formed into claws, is called a *crow-bar*. Both kinds are used by gunners, in working cannon during battle : they are also used generally for lifting and moving heavy masses through small spaces, as the materials of the mason, the ship-builder, the warehouseman, &c. A short crow-bar is the instrument of house-breakers for wrenching open locks or bolts, tearing off hinges, &c.

The common *claw-hammer*, for drawing nails, is another example. A boy who cannot exert a direct force of fifty pounds, may yet by means of this kind of hammer extract a nail to which half a ton might be quietly suspended,—because his hand moves through perhaps eight inches, to make the nail rise one-quarter of an inch. The claw-hammer also proves, that it is of no consequence whether the lever be straight or crooked, provided it produces the required difference of velocity between power and resistance. The part of the hammer resting on the plank is the fulcrum.

A *pincers* or *forceps* consists of two levers, of which the hinge is the common prop or fulcrum. In drawing a nail with steel forceps or nippers, we have a good example of the advantages of using a tool : 1, the nail is seized by the teeth of steel instead of by the soft fingers : 2, instead of the gripping force of the extreme fingers only, there is the force of the whole hand conveyed through the handles of the nippers : 3, the force is rendered perhaps six times more effective by the lever-



length of the handles : and 4, by making the nippers, in drawing the nail, rest on one shoulder as a fulcrum, it acquires all the advantages of the lever or claw-hammer for the same purpose.

*Common scissors* are also double levers, and those stronger *shears* with which, under the power of a steam-engine, bars and plates of iron are now cut as readily as paper is cut by the force of the hand.

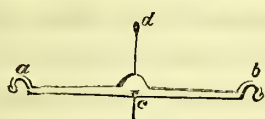
The common *fire-poker* is a lever. It rests on the bar of the grate as its prop, and displaces or breaks the caked coal behind as the resistance.

The *mast of a ship*, with sails set upon it, may be regarded as a long lever, having the sails as the power, turning upon the centre of buoyancy of the vessel as the fulcrum, and lifting the ballast or centre of gravity as the resistance. For this reason lofty sails make a ship heel or lean over greatly, and if used in open boats, are dangerous. In some of the islands in the Eastern and Pacific Oceans, for the sake of sailing swiftly, boats are used so extremely narrow and sharp, that to counteract the overturning tendency of their large sails, they have an *outrigger* or projecting plank to windward, on the extremity of which one or more of the crew may sit as a balance.

Perhaps no instance of the lever, with the prop between the forces, is more interesting than the *weighing-beam* : whether with equal arms, forming the common *scale-beam* ; or with unequal arms, forming the *steelyard*.

We have seen why quantities of matter attached at equal distances from the prop, must be equal to each other in order to balance. A lever, there-

fore, which enables us to place quantities thus exactly in opposition to each other, and which



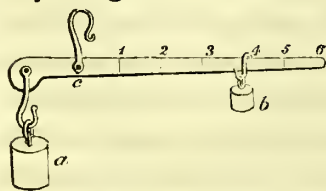
turns easily on its axis, becomes a weighing-beam. Of this the annexed figure shews a common form. The axis

or pivot at *c* is sharpened below, wedgelike, that the beam may turn easily, and that its centre of motion may be nicely determined ;—in a delicate balance for philosophical purposes, the axis is almost as sharp as a knife edge, and rests on some hard smooth surface of support, so as to turn with the weight of a small part of a grain. The scales also of a weighing-beam are suspended on sharp edges, to facilitate motion, and to determine nicely the points of suspension. If the two arms of a beam be not of perfectly equal length, a smaller weight at the end of the longer will balance a greater weight at the end of the shorter. An excess of half an inch in the length of a beam-arm, to which merchandize is attached, where the arm should be eight inches long, would cheat the buyer of exactly one ounce in every pound. This case might be detected instantly, by changing the places of the two things balanced ; for so, the lightest would be at the short arm, and would then appear doubly too light. A beam intended for delicate purposes, and required, therefore, to turn easily, must have its centre of gravity very near the axis on which the beam turns ; for if otherwise, the beam will be in the predicament of a ship with the ballast too high or too low : in the former case, when once inclined, it would fall over, and not to

recover itself; in the latter, it would tend to remain horizontal, and therefore would be less free to move. The proper situation of the centre of gravity is a little below the axis or line of support, that the beam may return with sufficient readiness from any state of inclination, to its horizontal position of rest.

There is a mode of arriving at very accurate results, even with a weighing-beam which is not itself accurately made, provided it has very free motion, *viz.* first, very nicely to balance in one scale the substance to be weighed, and then to remove it, and to put weights into the same scale, until a perfect balance is again produced. Such weights must be the exact equivalent or weight of the substance, however unlike to each other the arms of the balance may be. A projecting rod or plank or branch of a tree, may thus be made to answer the purpose of a weighing-beam, by attaching any substance to its extremity, and observing minutely how far such substance bends it, and then trying what weights would bend it as much.

The *steelyard* is a lever with unequal arms, and any weight, as *b*, on the long arm, will balance as much more weight, as *a*, on the short arm, as the former is supported further from the fulcrum than the latter. Thus, if the hook at the short end be one inch from the centre of support *c*, a pound weight *b*, on the long arm at four inches, will balance four pounds, *a*, at



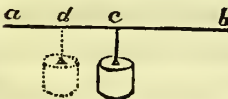
the short arm. This supposes, however, that the steel-yard when bare hangs horizontally, from having a greater mass of matter in the short arm to counterbalance the long slender arm from which the shifting weight hangs. When this is not the case, a corresponding allowance has to be made.

The Chinese, who are so remarkable for the simplicity to which they have reduced all their common implements, weigh any small objects by a delicate pocket steelyard. It is a rod of wood or ivory, about six inches long, with a silk cord passing through it at a particular part, to serve as a fulcrum, and with a sliding weight on the long arm, and a small scale attached to the short one.

The following are examples of levers with both forces on the same side of the prop, and where the more distant force acts as the power.

A common wheelbarrow is a lever, in using which a man bears as much less than the whole weight of the load, as the centre of gravity of the load is nearer to the axle of the wheel than to his hands.

When two porters carry a load placed midway between them, on a pole, they share it equally, that is to say, each bears a half, for the pole becomes a lever, of which each porter is a fulcrum, as regards the other; but if the load be nearer to one end than to the other, he to whom it is nearest bears proportionally more of its weight. A load

 at *c* is equally borne by a porter at *a* and by one at *b*; but a load at *d* gives three-quarters of its



weight to the man at  $a$ , and only one-quarter to him at  $b$ .

Two horses drawing a plough, act from the ends of a cross bar, of which the middle usually is hooked to the plough. The horses must thus pull equally, to keep the bar directly across. When on heavy land, three horses are yoked, and two of them are made to draw from one end of the bar, it must be attached to the plough by a hook, not at its middle, but half as far from one end of it as from the other.

The oar of a boat is a lever of this kind, where singularly the purpose of fulcrum is served by the unstable water.

The common nut-crackers furnish another instance, by the lever-power of which a person can break a shell many times stronger than he could break with the bare fingers.

The consideration of this kind of lever explains, why a finger caught near the hinge of a shutting door is so much injured. The momentum of the door acts by a comparatively long lever, upon a resistance placed very near the fulcrum. Children pinching their fingers near the hinge of a door, or of the fire-tongs, which furnishes a similar case—wonder why the bite is so keen.

The phenomenon of the branch of a tree giving way, when in autumn overloaded with fruit, or in winter with snow, also exhibits the action of this kind of lever. The resistance is the cohesion of the upper side of the branch to the tree, and the fulcrum is the part below which is last broken.



The following are examples of the lever, where the two forces are on the same side of the pivot, but where that nearest to the pivot acts as the power. In this kind, the power is more intense than the resistance.

The hand of a man who pushes open a gate while standing near the hinges, moves through much less space than the end of the gate, and hence must act with great force.

When a man uses the common fire-tongs, the ends move much farther than his fingers, and therefore with less strength. No one fears a pinch with the ends of the fire-tongs.

The most beautiful and remarkable instances of this modification of lever are in the limbs of animals. The object in these was to give to the extremities great range and freedom of motion, without clumsiness of form; and it has been attained most perfectly by the tendons or ropes which move them being attached near to the joints, which are the pivots or fulcra of the bone-levers.

In the human arm, the deltoid muscle, which forms the cushion of the shoulder, by contracting its fibres less than an inch, raises the elbow twenty inches; and of course, if it overcome a force of fifty pounds at the elbow, it must itself be acting with a force at least twenty times as intense, or of one thousand pounds.—What extraordinary strength of muscle, then, is displayed by a man who lifts another at the end of his extended arm; yet this feat is frequently accomplished, and even on both sides of the person at once.

How powerful again must be the wing-muscles of birds, which, by this kind of action, sustain themselves in the sky for many hours together. The great albatross, with wings extended fourteen feet or more, is seen in the stormy solitudes of the Southern Ocean, accompanying ships for whole days, without ever resting on the waves.

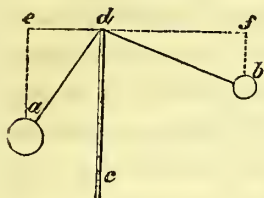
A little contraction of the glutæi muscles of the hips gives to the human step a length of four feet.

While the erroneous opinion prevailed, that machines *increased* power, instead of, as they do, merely *accommodating* forces to purposes, this last kind of lever, where a great force acting through a short distance is made to gain great extent of motion and other benefits, was regretted by many as a most unprofitable contrivance, and was called the *losing lever*.

It is almost unnecessary to say, that the same rule of comparative velocities ascertains the relations required between power and resistance, where a combination of levers is used, as where there is only one. If a lever which makes *one* balance *four*, be applied to work a second lever which does the same, *one* pound at the long arm of the first will balance *sixteen* pounds at the short arm of the second, and would balance *sixty-four* at the short arm of a third such, &c.

The general rule for the lever, that a force may be less intense the farther it is from the pivot, supposes always that the force acts at right angles, or directly across the lever; for if there be any obliquity, there is a corresponding diminution of

effect, as explained under the head of *resolution of forces*, at page 84. For instance, one pound at *b*



on the end of the long arm of the bent lever *b d a*, because its weight does not act directly across *b d*, has influence only as if it were acting directly at the end of a shorter

horizontal arm *d f*; and the two-pound weight at *a* acts only as if it were on a horizontal arm at *e*; now *e* being only half as far from the centre as *f*, two pounds at *a*, in the position of the lever here shewn, would just balance the one pound at *b*.

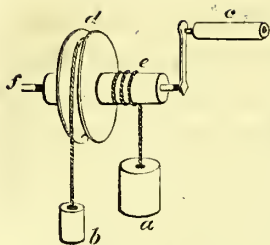
In every case, the exact influence of weights is known by referring them to places directly above or below them, on a supposed horizontal lever *e f*. What is called a *bent-lever balance*, is made on the principle here explained. It has on one side a heavy weight as at *a*, and on the other side a scale attached at *b*; and the weight of any thing put into the scale is indicated by the position then assumed by the lever, marked by the point at which it cuts an arc of divisions placed behind it. In any common weigh-beam, the point of suspension of the scales being a little below the axis of motion of the beam, there is a degree of the property of the bent-lever balance, and enough to require notice in very nice experiments.

### “ *The Wheel and Axle* ”

is the next to be mentioned of the *simple machines*. The letter *d* here marks a wheel, and *e* an axle affixed to it; and we see that in turning together,

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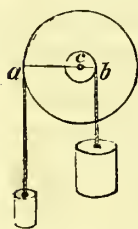
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the wheel would take up or throw off as much more rope than the axle, as its circumference or diameter were greater than that of the axle. If the proportions were as

four to one, one pound at *b*, hanging from the circumference of the wheel, would balance four pounds at *a*, hanging from the opposite side of the axle. The proportions are equally indicated, and are usually expressed by comparison of the diameters of the wheel and the axle.

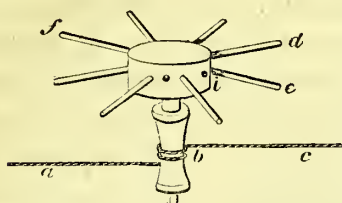
This figure represents the same object as the last, viewed endways. It explains why the wheel with its axle has been called a perpetual lever; for the two weights hanging in opposition, on the wheel at *a*, and on the axle at *b*, are always as if they were connected by a horizontal



lever at *a c b*, of which the arms are respectively the diameters of the wheel and the axle, turning on the centre *c* as the prop; and while a simple lever could only lift through a small space, it is evident that this construction will lift as long as there is rope to be wound up.

A common crane for raising weights, consists of an axle to wind up or receive the rope which carries the weight, and of a large wheel at the circumference of which the power is applied. The power may be animal effort exerted on the rim or outside of the wheel, or the weight of a man or beast walking within it, and moving it as a squirrel moves the cylinder of his cage.

The *capstan* used on board of ships, is merely a



large upright axle or spindle *b*, which by turning pulls the cable or rope *a b c*; and it is moved by the

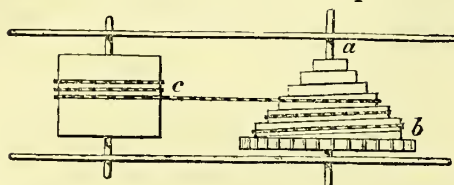
men pushing at the capstan-bars *d*, *e*, *f*, &c., which for the time are stuck into holes made for them in the broader part or drum, usually appearing above the deck, at the top of the spindle. These bars may be considered as the spokes of a large wheel, and the effect produced by a man working at one of them is in proportion to his distance from the centre. The capstan is chiefly used on board ships for lifting the anchor, and for doing any other very heavy work; but it is also applied to certain purposes on shore.

The common *winch* (represented as attached to the wheel and axle in page 168, at the letter *c*), with which a grindstone is turned, or a crane worked, or a watch wound up, is really in principle a wheel: for the hand of the worker describes a circle, and there is no difference in the result whether an entire wheel be turning with the hand or only a single spoke of a wheel.

That part of a common watch called the *fusee* is as beautiful an illustration of the principle of the wheel and axle now under consideration, as it is a useful and ingenious contrivance. The spring of a watch, immediately after winding up, being more strained, is acting more powerfully than afterwards when slacker, and if there were no



means of equalizing its action, it would destroy the wished-for uniformity in the motion of the time-piece. The fusee is this means. It may be considered as a barrel or spindle, gradually dimi-

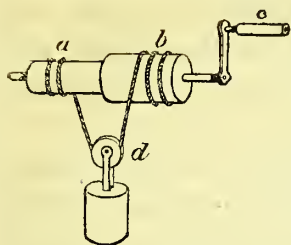


nishing from its large end *b*, to its small end *a*, with the surface cut into

a spiral groove to receive the chain, by pulling at which the spring in the box *c* moves the watch. Now when the watch has been wound up, by a key applied on the axis of the fusee, the fusee is covered with the chain up to the small end *a*, and the newly bent and strong spring begins to pull by this small end or short lever; and afterwards, exactly as the spring becomes relaxed and weaker, it is pulling at a larger and larger part of the fusee-barrel, and so keeps up an equal effect on the general movement.

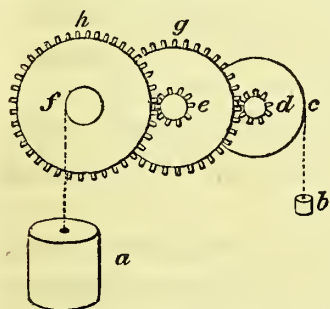
A large fusee in place of a common cylindrical axle, is often used with a winch, for drawing water by bucket and rope from very deep wells. When the bucket is near the bottom of the well, and the labourer has to overcome the weight of the long rope, in addition to that of the bucket and water, he does so more easily by beginning to wind the rope on a small axle, that is to say, on the small end of the fusee; and in proportion as the length of rope diminishes, he lifts by a larger axle.

By the double axle *a b*, very unequal intensities of force may be balanced. We see that in turning



it, a rope unwinding from the small end *a*, is taken up by the large end *b*, turn for turn, and that the rope below must be shortened at each turn by the difference between the circumference of the ends *a* and *b*. If the weight rise half an inch only, while the handle of the winch describes a circle of fifty inches; one pound force at the winch would balance one hundred pounds at *d*.

By means of a wheel, which is very large in proportion to its axle, forces of very different intensities may be balanced, but the machine becomes of inconvenient proportions. It is found preferable, therefore, when such an end is desired, to use a combination of wheels of moderate size. In



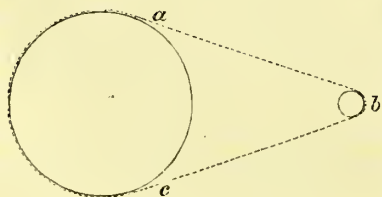
the adjoining figure three wheels are seen thus connected. Teeth on the axle *d*, of the first wheel *c*, acting on six times the number of teeth in the circumference of the second wheel *g*, turn it only once for every six times that *c* turns; and in the same manner the second wheel, by turning six times, turns the third wheel *h* once; the first wheel, therefore, turns thirty-six times for one turn of the last; and as the diameter of the wheel *c*, to which the power is applied, is three times as great as that of the axle *f*, which has the resistance: three times thirty-six, or one hundred and

eight, is the difference of velocity, and therefore of intensity, between weights or forces that will balance here.—An axle with teeth upon it, as *d* or *e*, is called a pinion.

On the principle of combined wheels, *cranes* are made, by which one man can lift many tons. It is even possible to make an engine, by means of which a little windmill, of a few inches in diameter, should tear up the strongest oak by the roots; but of course it would require a very long time for its work.

The most familiar instances of wheel-work are in our clocks and watches. One turn of the axle on which the watch-key is fixed, is rendered equivalent, by the train of wheels, to about four hundred turns or beats of the balance-wheel; and thus the exertion during a few seconds, of the hand which winds up, gives motion for twenty-four or thirty hours. By increasing the number of wheels, time-pieces are made which go for a year: if the material would last, they might easily be made to go for a hundred or a thousand years.

Wheels may be connected by bands as well as by teeth. This is seen in the common spinning-



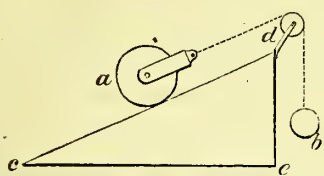
wheel, turning-lathes, grind-stones, &c. &c.

A spinning-wheel, as *a c*, of thirty inches in circumference, turns by its band a pirn or

spindle of half an inch, *b*, sixty times for every turn of itself.

*“The inclined plane”*

is the third means, which we shall describe, of



balancing, by solid media, forces of different intensities. A force pushing a weight from *c* to *d*, only raises it through the per-

pendicular height *e d*, by acting along the whole length of the plane *c d*; and if the plane be twice as long as it is high, one pound at *b*, acting over the pulley *d*, would balance two pounds at *a*, or any where on the plane: and so of all other quantities and proportions, as already explained under the head of “Resolution of forces,” at page 86.

A horse drawing on a road where there is a rise of one foot in twenty, is really lifting one-twentieth of the load, as well as overcoming the friction and other resistance of the carriage. Hence the importance of making roads as level as possible; and hence our forefathers often erred in carrying their roads directly over hills, for the sake of straightness considered vertically, where by going round the bases of the hills they would scarcely have had greater distance, and would have avoided all rising and falling. Hence, also, a road up a very steep hill must be made to wind or zig-zag all the way; for to reach a given height, the ease of the pull to the horses is greater exactly as the road is made longer. This rule of road-making is exhibited remarkably in various parts of the world, where hills with almost perpendicular face, have very safe and commodious roads upon them, leading to forts or residences near their summits.

An intelligent driver, in ascending a steep hill on which there is a broad road, winds from side to side of the road all the way to save his horses a little.

The railways of modern times offer a beautiful illustration of this subject. They are made generally quite level, so that the drawing horse or steam-engine has only to overcome the friction of the carriage; or, where heavy loads are passing only in one direction, as from mines, they are made to slope a very little, leaving to the horse or other power only the office of regulating the movement.

A hogshead of merchandize, which twenty men could not lift directly, is often seen moved into or out of a waggon, by one or two men, who have the assistance of an inclined plane. In some canals, or rather particular situations on canals, the loaded boats are drawn up by machinery on inclined planes, instead of being raised by water in locks, as is the usual mode.

It is supposed that the ancients (the Egyptians particularly) must have used the inclined plane, to assist in elevating and placing those immense masses of stone, which still remain from their times, specimens of their gigantic architecture.

Our common stairs are inclined planes in principle; but being so steep, are cut into horizontal and perpendicular surfaces, called steps, that they may afford a firm footing.

We may here recall that a body falling freely, in obedience to gravity, descends about sixteen feet in the first second, and that if made to descend on an inclined plane, it moves just as much less quickly (besides the loss from the friction and

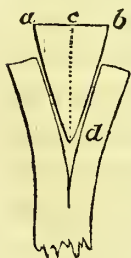


the turning produced) as the length of the plane is greater than the height. On a plane sloping one foot in sixteen of its length, a body would descend only one foot in the first second.

The descent of a pendulum in its arc is investigated mathematically by the laws of the inclined plane. And the laws of the inclined plane itself are mathematically examined by the principle of the *resolution of forces*, explained at p. 86.

### “ The wedge ”

is merely an inclined plane forced in between resistances to separate or overcome them, instead of, as in the last case, being stationary while the resistance is moved along its surface. The same rule as to mechanical advantage has been applied to the wedge as to other simple machines ; the force acting on a wedge being considered as moving through its *length*  $cd$ , while the resistance yields to the extent of its breadth  $ab$ . But this rule is far from explaining the extraordinary power of a wedge. During the tremor produced by the blow of the driving-hammer, the wedge insinuates itself, and advances much more quickly than the above rule anticipates.



The wedge is used for many purposes ; as for splitting blocks of stone and wood ; for squeezing strongly, as in the oil-press ; for lifting great weights, as when a ship of war, in dock, is raised by wedges driven under the keel, &c.

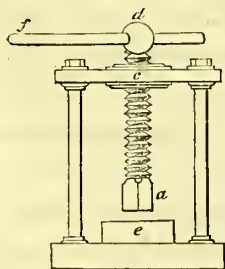
An engineer in London, who had built a very

lofty and heavy chimney, common to all his steam-engines and furnaces, found after a time that, owing to a defect in the foundation, it was beginning to incline. However, by driving wedges under one side of it, he succeeded in restoring it to perfect perpendicularity.

Nails, awls, needles, &c. are examples of the wedge; as are also all our cutting instruments, knives, razors, the axe, &c. These latter are often used somewhat in the manner of a saw—which is a series of small wedges,—by pulling then lengthwise at the same time that they are pressed directly forward against the object. They themselves, indeed, when viewed through a microscope, are seen to be but finer saws. It appears that the vibration of the particles produced by the drawing of a saw, enables its edge to insinuate itself more easily. The sharpest razor may be pressed directly against the hand with considerable force, and will not enter, but if then drawn along ever so little, it starts into the flesh.

### “ *The screw* ”

is another of the simple machines. It may be called a winding wedge, for it has the same relation to a straight wedge that a road winding up a hill or tower has to a straight road of the same length and acclivity.



A screw may be described as a spindle *a d*, with a thread wound spirally round it,—turning or working in a nut *c*, which has a

corresponding spiral furrow fitted to receive the thread. The nut is sometimes called the female screw. Every turn of the screw carries it forward in a fixed nut, or draws a moveable nut along upon it, by exactly the distance between two turns of its thread: this distance, therefore, is the space passed through by the resistance, while the force moves in the circumference of the circle described by the handle of the screw, as at *f* in the figure. The disparity between these lengths or spaces is often as a hundred or more to one; hence the prodigious effects which a screw enables a small force to produce.

Screws are much used in presses of all kinds: as in those for squeezing oil and juices from such vegetable bodies, as linseed, rapeseed, almonds, apples, grapes, sugar-cane, &c.: they are used also—in the cotton-press, which reduces a great spongy bale, of which a few, comparatively, would fill a ship, to a compact package, heavy enough to sink in water;—also, in the common printing-press, which has to force the paper strongly against the types:—a screw is the great agent in our coining machinery,—and in letter-copying machines:—it is a screw which draws together the iron jaws of a smith's vice, &c. The screw, although producing so much friction as to consume a considerable part of the force used in working it, is an exceedingly useful contrivance.

As a screw can easily be made with a hundred turns of its thread in the space of an inch, at perfectly equal distances from each other, it enables the mathematical instrument-maker to mark divisions on his work, with a minuteness and accuracy

quite extraordinary. If we suppose such a screw to be pulling forward a plate of metal, or pulling round the edge of a circle, over which a sharp-pointed steel marker can be let down perpendicularly, always in the same place, the marker, if let down once for every turn of the screw, will make just as many lines on the plate as the screw makes turns; but if made to mark at every hundredth or a thousandth of a turn of the screw, which it will do with equal accuracy, it may draw a hundred thousand distinct lines in one inch.

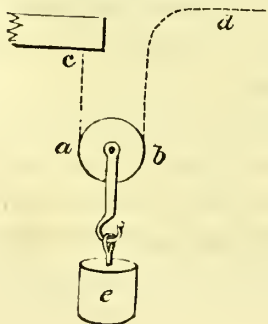
The instruments called micrometers, by which the sizes of the heavenly bodies and of microscopic objects are ascertained, are worked by fine screws.

A *perpetual screw* is the name given where a screw acts on the teeth of a wheel, so as to produce a continued rotation of the wheel.

A common cork-screw is the thread of a screw without the spindle, and is used, not to connect opposing forces, but merely to enter and fix itself in the cork. Complicated cork-screws are now made, which draw the cork by the action of a second screw, or of a toothed rod or rack and pinion.

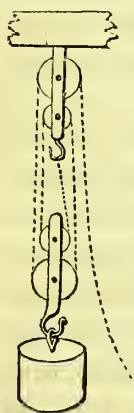
### “ The pulley ”

is another *simple machine*, by which forces of different intensities may be balanced. A simple pulley consists of a wheel as *a b*, which rests with its grooved circumference on the bend of a rope, *c a b d*, and to the axis of which the weight or resistance is attached, as at *e*.



In such a construction, it is evident that the weight (let it be supposed ten pounds) is equally supported by each end of the rope, and that a man holding up one end, only bears half of the weight, or five pounds; but to raise the weight one foot, he must draw up two feet of rope; therefore, with the pulley he is as if lifting five pounds two feet, where, without the pulley, he would have to lift ten pounds one foot.

Many wheels may be combined together, and in many ways to form compound pullies. Wherever there is but one rope running through the

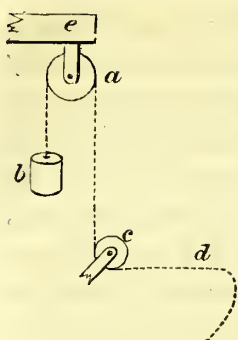


whole, as shewn here, the relation of power and resistance is known by the number of folds of the rope which support the weight. Here there are four supporting folds, and a power of one hundred pounds would balance a resistance of four hundred. As persons using pulleys generally find it more convenient to stand upon the ground than to go up and apply their force directly to one of the supporting ropes,

the last of these is commonly made to pass over a wheel above, and to come down apart from the others, as shewn here. This portion not being directly connected with the weight, adds convenience to the pulley, but is not to be counted with the others, in estimating the relation of the power and resistance.

In *fixed pulleys*, like those shewn at *a* and *c*, there is no mechanical advantage, for the weight just moves as fast as the power; yet such pullies





are of great use in changing the direction of forces. A sailor without moving from the deck of his ship, by means of such a pulley, may hoist the sail or the signal-flag to the top of the loftiest mast. And in the building of lofty edifices, where heavy loads of material are to be sent up every few minutes, a horse, trotting away with the end of the rope from *d*, in a level court-yard, causes the charged basket *b* to ascend to the summit of the building as effectually as if he had the power of climbing, at the same rate, the perpendicular wall.

There is a case, however, in which a fixed pulley may seem a balancer of different intensities of force; *viz.* where one end of a rope is attached to a man's body, and the other is carried over a pulley above, and brought down again to his hands;—for safety this end also should be attached to his body. By using the hands then to pull with force equal to half his weight, he supports himself, and may easily raise himself to the pulley. A man, by a pulley thus employed, may let himself down into a deep well, or from the brow of a cliff, with assurance of being able easily to return, although no one be near to help him; and cases have often occurred where, by such means, a fellow-creature's life might have been saved, or other important objects attained. How easily, for instance, might persons either reach or escape from the elevated windows of a

house on fire, by such a pulley, which might readily be found and used where ladders could not be obtained!—This kind of pulley furnishes a convenient means of taking a bath from a ship's stern windows, &c.

The chief use of the pulley is on ship-board. It is there called a block, although strictly speaking, the block is only the wooden mass which surrounds the wheel or wheels of the pulley. It aids so powerfully in overcoming the heavy strains of placing the anchor, hoisting the masts and sails, &c., that by means of it a smaller number of sailors are rendered equal to the duties of the ship. Pulleys are also used on shore, instead of cranes and capstans, for lifting weights, and overcoming other resistances.

Surgeons, in former days, when they trusted rather to force than to the address which better information gives, used pulleys much to help in the reduction of luxations,—but often hurtfully, from not understanding the force of the pulley. A good surgeon now rarely needs a pulley, and he who should ignorantly stretch his patient on the rack, would be well requited by similar treatment.

The cranks of bell-wires, seen in the corners of our rooms, are bent levers nearly equivalent to fixed pulleys.

There is no reason, but old usage, why the application of *mechanical power* should be confined to the six contrivances now explained, for those of which the account is yet to follow equally deserve it ; and, as will be seen under hydros-

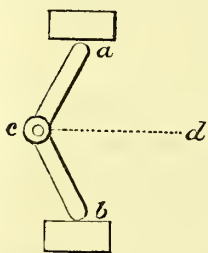
tatics and pneumatics, the most powerful mechanical engines do not belong to solids at all.

*Engine of oblique action*, is a title which may include a considerable variety of contrivances for connecting different velocities:

Suppose  $c a$  and  $c b$  to represent two strong rods connected together, like a carpenter's folding rule, by a hinge or joint at  $c$ . If the distant ends be made to bear against notches in two obstacles, at  $a$  and  $b$ , and by force then applied to  $c$ , either to push or to pull, the joint  $c$  be straightened or carried towards  $d$ , the joint  $c$  will move through a much greater space than the simultaneous increase of distance produced between  $a$  and  $b$ ; and, in proportion to the disparity, the power applied at  $c$  will overcome a more intense resistance at the extremities. The mechanical power of this contrivance increases rapidly, the nearer the jointed rods approach to straightness.

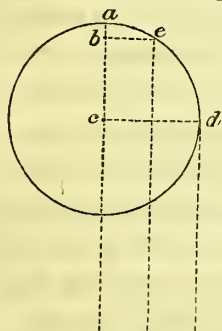
If we suppose the end  $a$  to be steadied by a hinge on frame-work, and the end  $b$  to bear upon that part of a printing-press which carries the paper against the types, we have imagined the simple press, called, from its contriver, the Russel-press. A man's force at  $d$ , at the moment when the rods are drawn nearly to a straight line, becomes equivalent to a pressure of many tons.

For the same reason, that by urging  $c$  towards  $d$ , in the last figure, the extremities  $a$  and  $b$  are separated with great force, so by urging  $c$  in the



contrary direction, the extremities would be drawn together with corresponding force: and if we suppose  $a c b$  to be part of a rope coming through pulleys at  $a$  and  $b$ , to one end of which rope beyond  $a$ , great resistance is attached, one man, by pulling at  $c$ , may move a weight or resistance many times greater than he could move by his direct power.

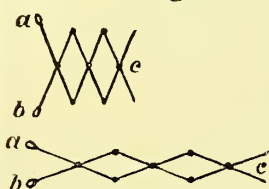
The following is another mode of connecting an oblique and a direct force, so as to balance them, although of different intensities.—If to turn a wheel (represented here by the circle), a weight be suspended from  $d$ , it is acting directly, for it descends just as fast as the circumference of the wheel moves, and would therefore be impelling



with its whole strength: but if it were suspended from the point  $e$ , it would then be acting obliquely to the motion of that part of the wheel, and from not descending so fast as if at  $d$ , it would have as much less effect on the wheel, than if there, as the line  $e b$  is shorter than the line  $d c$ . The reason of this will be understood by referring to the subjects of *resolution of forces*, and of *bent levers*, in former parts of the work. For the same reason, if such a wheel were used in lifting weights, a man turning it could lift as much more attached at the point  $e$  than at the point  $d$ , as the line  $d c$  is longer than  $e b$ . A man turning this wheel in the direction from  $e$  to  $a$ , with a weight hanging at  $e$ , would be lifting that weight exactly as if he were rolling it up the inclined plane or curve  $e a$ . This figure is

useful in explaining the varying intensity of the action of a crank or winch, in different parts of its revolution, and of the combination of levers used in the *Stanhope printing press*, in their different positions: it explains also the degrees of strength and support afforded by oblique stays in buildings and in ships' rigging, and many other kindred matters.

The arrangement of cross-jointed wires, represented here, connects different velocities, and therefore is really a mechanic power. It has been applied to some curious purposes, but to none of much utility. By pressing the ends *a* and *b* towards each other, the wires, from being in the position represented in the upper figure, immediately assume the position represented in the lower; so that the end *c* darts outwards much farther than the ends *a* and *b* approximate.



Different intensities of force are balanced, although not simultaneously, by the following means; which therefore, according to the old idea, have some claim to the name of *mechanic powers*.

A man may have a purpose to effect, which a forcible downward push would accomplish: but his body being too weak to give that push directly, he may employ a certain time in carrying a weight to such an elevation above his work, that when let fall its momentum may do what is required. Here the continued effort of the man in lifting the



weight, to a height of perhaps thirty feet, may be just sufficient to produce a blow which will cause a stake or pile to sink into the earth one inch ; and the contrivance has therefore balanced forces, of which the relation as to intensity is marked by the spaces thirty feet and an inch.

So also *hammers, clubs, battering-rams, slings, &c.* are machines which enable a continued moderate effort to overcome a great but short resistance.

The *fly wheel*, which by persons ignorant of natural philosophy has often been accounted a positive power, in common cases merely equalizes the effect of an irregular force. In using a winch to turn a mill, for instance, a man does not act with equal force all round the circle ; but a heavy wheel fixed on the axis moderates acceleration, and receives or absorbs momentum, while his action is above par, and returns it again, giving it to the machine, while his action is below par, thus equalizing the movement. And in the common instances of circular motion produced by a crank, as when by the pressure of the foot on a treadle, we turn a lathe or grindstone, or spinning-wheel, the force is only applied during a small part of the revolution, or in the form of interrupted pushes ; yet the motion goes on steadily, because the turning grindstone, or wheel, or lathe, becomes a fly and reservoir, equalizing the effect of the force. In a steam-engine which moves machinery by a crank, the upward and downward pushes of the piston are converted, by means of a heavy fly-wheel, into a very steady rotatory motion.

A heavy wheel, however, has sometimes been

used as a concentrator of force or a mechanic power. By means of a winch, or a weight, or otherwise, motion or momentum being gradually accumulated in the wheel, is then made to expend itself in producing some sudden and proportionally great effect. Thus a man may lift a very heavy weight by first in any way giving motion to a fly-wheel, and then suddenly hooking a rope from the weight to the axle of the wheel, which rope being wound upon the axle, lifts the weight.

A fly wheel moved in the same manner, and containing the result of a man's action during perhaps one hundred seconds, if made to impel a screw-press, will, with one blow or punch, stamp a perfect medal, or from a rough flat plate of silver will form a finished spoon, or other utensil.

A spring, in the same sense, may become a mechanical power. A person may expend some minutes in bending it, and may then let fly its accumulated energy in an instantaneous blow. A gun-lock shews this phenomenon on a small scale. The slow bending of a bow, which afterwards shoots its arrow with such velocity, is another instance.

THESE, then, are the principal means which the solid state of bodies affords us of balancing forces of different intensities. We shall find other such means or mechanic powers belonging to liquids and airs. All of them are of inestimable value to man, by enabling him to accommodate the forces which he can command to any kind of work which he has to perform. Thus he makes his millstone

turn with the same velocity, whether it be moved by the slow exertion of a horse or bullock, walking in a ring, or by the quicker motion of a river gliding under the wheel, or by the rapid gush of a water-fall, or by the invisible swiftness of the wind. And again, each of these forces he can equally apply to turn the heavy millstone or to twist a cotton thread.

The wants of men seem first to have led them to use the *simple machines* for the purposes of raising great weights, or overcoming great resistances, and hence the name long used of *mechanic powers*,—particularly for the Lever, Wheel and Axle, Plane, Wedge, Screw, and Pulley : but the term conveys to the uninformed a false idea of their real nature, and has begotten the common prejudice with respect to them, that they *generate* force, or have a sort of innate power for saving labour. Now so far is this from being true, that in using them in any case, even more labour or bodily exertion is expended than would suffice to do the work without them. This assertion is intentionally rendered paradoxical to arrest attention, but its truth will appear from the following considerations.

One man may be able, with a tackle of pullies having ten plies of the rope, to raise a weight which it would require ten men to raise at once without pullies. But if the weight is to be raised a yard, the ten men will raise it by pulling at a single rope and walking one yard, while the one man at his tackle must walk until he has shortened all the ten plies of rope of one yard each ; that is, he must walk ten yards, or ten times as far as the

ten men did. In both cases, therefore, to accomplish the same end, we have just the same quantity of man's work expended, in the first, performed by ten men in one minute, in the second, by one man in ten minutes ; and if the work were of a nature to continue longer, let us say a whole day for the ten men, it would last ten days for the single man, and there would be ten days' wages of a man to pay in both cases : there is, therefore, no direct saving of human effort from using pullies ; indeed there is a loss, because of the great friction which has to be overcome. Now exactly the same is true of all other simple machines, or mechanic powers ; none of them save labour, in a strict sense of the phrase ; they only allow a small force to take its time to produce any requisite magnitude of effect, at the expence of additionally overcoming a certain amount of friction, or other such resistance.

The real advantages of these machines are such as the following :

That one man's effort, or any small power, which is always at command, by working proportionally longer, will answer the purpose of the sudden effort of many men, even of hundreds or thousands, whom it might be most inconvenient and expensive, or even impossible, to bring together.

A ship's company of a few individuals easily weighs a heavy anchor by means of the capstan.

A solitary workman, with his screw or other engine, can press a sheet of paper against types, so as to take off a clear impression ; to do which without the press, the direct push of fifty men



would scarcely be sufficient ; and these fifty men would be idle and superfluous except just at the instants of pressing, which occur only now and then. In this way the screw may be said to do the work of fifty men, for it is as useful.

A man with a crow-bar may move a great log of wood to a convenient place, where twenty men would have been required to move it without the crow-bar ; and although the single man takes twenty minutes, perhaps, to do what the many men would have done in one minute, as the twenty might not have been wanted again for the rest of the day, the crow-bar may really be as useful as the twenty men.

It is so important to have correct notions on the subject of the simple machines or mechanical powers, that more space has been here allotted to the explanation of the general principle, than has been usual in such works. After the examination which it has now undergone, however, the author hopes that none of his readers will have difficulty in conceiving clearly, that “ whatever, through a machine, is gained in power, is lost in speed or in time, and *vice versa* ”—or will have difficulty in detecting immediately any common fallacy connected with the subject ;—as that of supposing, for instance, that a lever, or great pendulum, or spring, or heavy fly-wheel, &c. can ever exert more force than has passed into it from some source of motion.

“ *By solid connecting parts, also, the direction of any existing motion or force may be changed.*



*Hence the endless variety of COMPLEX MACHINES.”*  
(Read the Analysis at p. 125.)

It is this power of changing the direction of motion, added to the power of connecting and adjusting various intensities of force and resistance by the simple machines last described, which has enabled man to make complex machines, rivalling in their performances the nicest work of human hands. It would be endless to attempt the enumeration of the modes in which the direction of motions may thus be changed, for it would be to enumerate and describe the whole apparatus of the arts and sciences; but we shall advert to a few as specimens.

*Straight motion changed into rotatory.*—The straight motion of wind or water becomes rotatory in wind or water-wheels.—The straight-downward pressure of the human foot, acting at intervals on a treadle and crank, turns round the grindstone, and common lathe, and spinning-wheel. The alternate rising and falling of the piston of a steam-engine is made, by means of a crank, to turn the great fly-wheel and any other wheels which a steam engine may move.

*Rotatory motion into straight.*—An axle in turning will wind up a rope, and lift a weight in a straight line.—A crank on a turning axle, if connected with a pump-rod, will work the piston up and down; or it will work a saw.—Pallets or teeth on a turning-wheel act on the handle of a great forge-hammer, so that every one in passing lifts the hammer and produces a blow

We need not multiply instances. By a visit to great manufacturing towns, or, indeed, by simply directing the eyes to what is passing around, in any part of the civilized world, we discover miracles of mechanic art :—machines driven by wind, water or steam for grinding corn ;—machines for sawing wood and giving it various forms ;—machines in which rods of metal are seized between great rollers, and are flattened at once into thin plates, as if they were of clay, and these plates again are slit into bars or ribbons ;—spinning machines, which perform their delicate office even more uniformly than human hands, forming thousands of threads at once, in obedience to the impulse of a single steam-engine ;—weaving machines, which accomplish their difficult task with the most admirable perfection ;—paper-making engines, which convert worn-out and apparently useless remnants of our apparel, into the uniform and beautiful texture of paper, a texture which, with the farther assistance of the pen, or types, or engraved plate, becomes a magic conservatory of mind, shutting up among its folds the brightest effusions of genius, and ready at any instant to disclose them again to the delighted student, nothing changed after revolving centuries ;—coining machinery, which from a bar or plate of metal cuts out and stamps thousands of beautiful medals in an hour, and keeps an exact record of its work ;—cranes,—pile-engines,—turning-lathes,—time-pieces,—all the implements of agriculture, of mining, of navigation, &c. &c. If Aristotle deemed the title or definition of *tool-using animal* appropriate to man two thousand years ago, what title should be given now ?

In many of the complex machines, several of the simple ones are found as elements ; and in the same machine may be comprised many of the means of changing the direction of motion.

“ *Friction.*” (Read the Analysis, page 125.)

In estimating the effects of mechanical contrivances, by the rule of the comparative velocities of the power and resistance, there is an important correction to be made, on account of the mutual friction of the moving parts. In the steam-engine, where the rubbing parts are numerous, the loss of power from friction often amounts to one-third of the whole.

Impediment from friction seems to be owing to two causes : 1st, a degree of cohesive attraction between the touching substances ; 2d, the roughness of these surfaces, even where, to the naked eye, they appear smooth.

It is supposed to be, because the roughnesses, or little projections and cavities, in pieces of the same or of homogeneous substances mutually fit each other, as the teeth of similar saws would, so as to allow the bodies in a degree to enter into each other, that the friction is greater between such, than between pieces of different or of heterogeneous substances with dissimilar grain.

The friction of one piece of iron, wood, brick, stone, &c. on another piece of the same substance, has been measured by using the second piece as an inclined plane, and then gradually lifting one end of it until the upper mass began to slide,—the inclination of the plane, just before the sliding

commences, is called the angle of repose. This angle, different for different substances, is found to be, for metals, generally such as to mark that the force required to overcome the friction between small pieces of them is equal to about a fourth of the weight of the moving piece, and for woods it is about a half. But for large pieces or great pressures, the friction is proportionately much less.

It is this angle in the substances concerned, which determines the degrees of acclivity which can exist in the sides of hills composed of sand, gravel, earth, &c., in the banks of canals, rivers, &c.

If the thread of a screw winds round the spindle with an angle less than this, the screw can never recoil or slide back from force acting against its point.

But for friction, men walking on the ground or pavement would always be as if walking on ice; and our rivers, that now flow so calmly, would all be frightful torrents. Friction is therefore in these cases of great use to men.

Friction is useful also, when it enables men, out of the comparatively short fibres of cotton, flax, or hemp, to form their lengthened webs and cordage,—for it is friction alone, consequent upon the interweaving and twisting of the fibres and threads, which keeps the material of these fabrics together.

The following means are used to diminish friction between rubbing surfaces; and they are used



singly or in combination, according to circumstances.

1. Making the rubbing surfaces smooth :—but this must be done within certain limits, for great smoothness allows the bodies to approach so near that a degree of cohesion takes place.

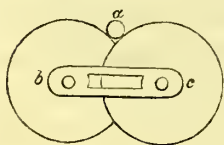
2. Letting the substances which are to rub on each other be of different kinds. Axles are made of steel, for instance, and the parts on which they bear are made of brass : in small machines, as time-keepers, the steel axles often play in agate or diamond. The swiftness of a skater depends much on the great dissimilarity between steel and ice.

3. Interposing some lubricating substance between the rubbing parts ; as oils for the metals, soap, grease, black-lead, &c. for the woods. There is a laughable illustration of this in the holiday sport of soaping a lively pig's tail, and then offering him as the prize of the clever fellow who can catch and hold him fast by his slippery appendix.

4. Diminishing the extent of the touching surfaces ; as in making the rubbing axis of a wheel very small.

5. Using wheels, as in wheel-carriages, instead of dragging a rubbing load along the ground. Castors on household furniture are miniature wheels.

6. Using what are called friction-wheels ;—



which still farther diminish the friction even of a smooth axis, by allowing it to rest on their circumferences, which turn with

it. Here *a* represents the end of an axis, resting on the exteriors of two friction wheels, *b* and *c*.



7. Placing the thing to be moved on rollers or balls, as when a log of wood is drawn along the ground upon rounded pieces of wood; or when a cannon, with a flat circular base to its carriage, turns round by rolling on cannon-balls laid on a hard level bed. In these two cases there is hardly any friction, and the resistance is merely from the obstacles which the rollers or balls may have to pass over.

Of all rubbing parts, the joints of animals, considering the strength, frequency, and rapidity of their movements, are those which have the least friction. The rubbing surfaces in these are covered, first, with a layer of elastic cartilage, and then with an exceedingly smooth membrane, over which there is constantly poured from glands around a fluid called synovia, more emollient and lubricating than any oil, and which is renewed constantly as may be required. We study and admire the perfection of animal joints, without being able very closely to imitate it.

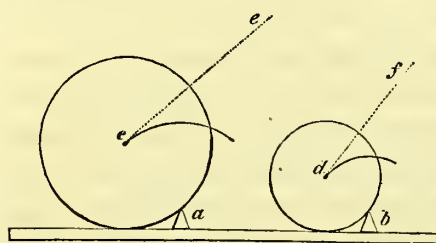
*Wheel carriages* merit notice here, as illustrating many of the circumstances connected with friction, and moreover as being among the most common of machines.

Wheel carriages have three advantages over the sledges for which they are the substitutes :

1. The rubbing or friction, instead of being between an iron shoe and the stones and irregularities of the road, is between the axle and its bush, of which the surfaces are smoothed and fitted to each other, and well lubricated.

2. While the carriage moves forward, perhaps fifteen feet, by one revolution of its wheel, the rubbing part, *viz.* the axle, passes over only a few inches of the internal surface of its smooth greased bush.

3. The wheel surmounts any abrupt obstacle on the road by the axle describing a gently rising slope or curve,—as shewn in this figure, where *a*



represents an obstacle, and where the curve from *c*, of which the beginning has the direction shewn by the line *ce*,

represents the path of the axle in surmounting it. The wheel is as if rising on an inclined plane, and gives to the drawing animal the relief which such a plane would bring. This kind of advantage is greater in a large wheel, for evidently the smaller wheel here represented, in having to surmount the same size of obstacle, has to rise in the steeper curve beginning at *d*,—but the difference of advantage, in this respect, is not so great as the difference of size. It is true, again, that a small wheel will sink to the bottom of a hole, where a larger one would rest on the edges as a bridge, and would sink less. The fore-wheels of carriages are usually made small, because such construction, by allowing the wheel to go under the body of the carriage, facilitates the turning of the carriage. It is not true, however, according to the popular prejudice, that the large hind-wheels of coaches,

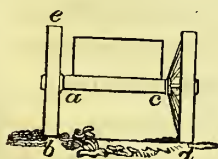
waggons, &c. help to push on the little wheels before them, as if the carriage were on an inclined plane resting on the wheels; but there is the accidental advantage, that in ascending a hill, when the horses have to put forth their strength, the load rests chiefly on the hind wheels, and in descending, when an increased resistance is desirable, the load falls chiefly on the fore-wheels.

From the causes mentioned in the last paragraphs, the difference in performing the same journey of a mile, by a sledge and by a wheel-carriage, is, that while the former has to rub over every roughness in the road and to be jolted by every irregularity, the rubbing part of the latter, the axle, glides very slowly over about thirty yards of a smooth oiled surface, in a gently waving line. Thus by wheels the resistance is reduced to about the hundredth part of what it is for a sledge.

On hilly roads, in descending, it is common to *lock* or fix one of the wheels of a carriage, and the horses have then to pull nearly as much as on a level road with the wheel free; shewing the effect of a little increase of friction.

The wheel of a carriage, simple as, from our extreme familiarity with it, it now appears to us, is a thing of very nice workmanship, and which has exercised much ingenuity.—It acquires astonishing strength, indeed that of the arch, from what is

called its *dished* form, seen here in the wheel *c*, as contrasted with the flat wheel *a*. In a wheel of this form, the extremity of a spoke cannot be displaced in-



wards, or towards the carriage, unless the rim of the wheel be enlarged, or all the other spokes yield at the same time, and it cannot be displaced outwards, or away from the carriage, unless the rim be diminished, or the other spokes yield in the opposite direction:—now the rim being strongly bound by a ring, or tire of iron, cannot suffer either increase or diminution, and the strength of all the spokes is thus by it conferred on each individually. In a *flat* wheel a given degree of displacement outwards or inwards of the extremities of a spoke, would less affect the magnitude of the circumference, and therefore the rim of such a wheel secures much less firmly. A watch-glass and a round piece of egg-shell are stronger than flat pieces of like substances, for the same reason that a dished wheel is stronger than a flat wheel.—The dished form of a wheel is farther useful by leaving more room between the wheels for the body of the carriage, and is useful also in this, that when the carriage is on an inclined road, and more of the weight consequently falls upon the wheel of the lower side, the inferior spokes of that wheel become nearly perpendicular, and thereby support the increased weight more safely. The strongest form of wheel is the *doubly dished*, that is, a wheel having half of the spokes passing from within to the rim, as from *c* to *d*, and the other half similarly from without. This form is adopted in the wheel recently constructed entirely of iron, in which there is the farther peculiarity that the load is supported more by hanging by the upper spokes than by resting on the lower.—When wheels, in-

stead of standing upright, like *b* and *d* shewn here, are made to incline outwards, as is common, owing to the ends of the axle-tree being bent down a little to give a security against the accident of the wheels falling off, the pull to the horses in deep or sandy roads is much increased; for an inclining wheel would naturally describe a curved and outward path, as is seen when a hoop or wheel-barrow inclines; and the horses, therefore, in drawing straight forward, have constantly to overcome the deviating tendency in all inclining wheels. This cause of resistance is still more remarkable when the wheels have broad rims. Such wheels must be conical, that is, of smaller diameter at the outer than at the inner edge, as the end of a cask is smaller than its middle, and then, as the iron hoops or tires which cover the different parts cannot all, by an equal number of turns, truly measure the same length of road, there will be a constant rubbing or grinding forward of the lesser rings, and a grinding backward of the larger, injuring the road, rapidly wearing the iron, and exhausting the strength of the pulling animals. Such wheels rolling free would describe a circular path, as is exemplified when a thimble, or drinking glass, or sugar-loaf, which also are conical, is pushed forward on any plane surface.

The application of springs to carriages, which is an improvement of comparatively recent date, not only renders them soft-moving vehicles on rough roads, but much lessens the pull to the horses. When there is no spring, the whole load must rise with every rising of the road, and if time



be given, must sink with every depression, and the depression costs as much labour as the rising, because the wheel must be drawn up again from the bottom of it; but in a spring-carriage moving rapidly along, only the parts below the springs are moved in correspondence with the road-surface, while all above, by the inertia of the matter, have a soft and even advance. Hence arises the superiority of those modern carriages, furnished with what are called *under-springs*, which insulate from the effect of shocks, all the parts, excepting the wheels and axletrees themselves. When only the body of the carriage is on springs, the horses have still to rattle the heavy frame-work below it over all irregularities, and then the wheels, as well as the structure generally, require to be of much greater strength and weight to bear the consequent shocks.

The subject of wheel carriages is interesting to medical men, from their having often to direct in transporting the sick or wounded.

It is perhaps difficult to conceive any thing more elegant and perfect, than the carriages of modern refinement; and therefore a man, who sees them gliding swiftly along the prepared levels and slopes of our present landscapes, and thinks of the clumsy vehicles on the bad roads of former times, may readily imagine that absolute perfection is at last attained. Yet we are perhaps now on the eve of a farther change, which for many purposes will be of greater importance than all that has yet been achieved—*viz.* the general adoption of rail-roads, with new-fashioned carriages to suit them. To all

who study such subjects, it is now known, that to drag a loaded waggon up one inconsiderable hill, costs more force than to send it thirty or forty miles along a level rail-way ; and the conclusion is obvious, that although the original expense of forming the level line might considerably exceed that of making an ordinary road, still, in situations of great traffic, the difference would soon be paid for by the savings, and when once paid, the savings would be as a profit for ever. To readers conversant with political economy, it would be superfluous to speak here of the advantages of any greater facility of intercourse, but to those who are not, the following reflections may be interesting.

In reviewing the history of the human race, we find that every remarkable increase in civilization has taken place very much in proportion to the facilities of intercourse offered in the particular situation. First, therefore, civilization grew along the banks of great rivers, as the Nile, the Euphrates, and the Ganges ; or along the shores of inland seas and archipelagos, as in the Mediterranean and the numerous islands of Greece ; or over fertile and extended plains, as in many parts of India. When the situation thus bound a great number of individuals into one body, the useful new thought or action of any one unusually gifted, and which, in the insulated state, would soon have been forgotten and lost, extended its influence immediately to the whole body, and became the thought or action of all who could benefit by it, besides that it was recorded for ever, as part of the growing

science or art of the community. And in a numerous society, such useful thoughts and acts would naturally be more frequent, because persons feeling that they had the eyes of a multitude upon them, and that the rewards of excellence would be proportionally great, would be excited to emulation in all the pursuits that could contribute to the well-being of the society. Men soon learned to estimate aright these and many other advantages of easy intercourse, and after having possessed themselves with avidity of the stations naturally fitted for their purposes, they began to improve the old and to make new stations. They created rivers and shores and plains of their own, that is, they constructed canals and basins and roads; and so, connected artificially regions which nature seemed to have separated for ever.—In the British isles, whose favoured children have taken so remarkable a lead in shewing what prodigies a wise policy may effect, the advantages arising from certain lines of canal and road first executed, soon led to numberless similar enterprizes, and within half a century the empire has been thus bound together in all directions: and it seems as if the noble work were now to be crowned by the substitution of level railways for many of the common roads and canals.\* Several rail-roads of short extent have already been established, and

\* These observations were first published (the substance had been written long before), soon after the Darlington rail-road, the first of any note intended for passengers, was opened. The Manchester and Liverpool rail-road has since then admirably verified the anticipations.

although they and the carriages upon them are far from having the perfection which philosophy says they will admit, the results have been very satisfactory. If we suppose the progress to continue, and the price of transporting things and persons to be thus reduced to a fourth of the present charge—and in many cases it may be less—and if we suppose the time of journeying with safety also to be reduced in some considerable degree,—of which there can be as little doubt—the general adoption of such roads would operate an extraordinary revolution and improvement in the state of society. Without in reality changing the distances of places, it would in effect bring all places nearer to each other, and would give to every spot in the kingdom the conveniences of the whole,—of town and country, of sea-coast and of highland district. A man, wherever residing, might consider himself virtually near to any other part, when at the expense of time and money now expended in travelling a short way, he might travel very far, and he would thus find remarkably extended the sphere both of his business and of his pleasures. The over-crowded and unhealthy parts of towns would scatter their inhabitants into the country ; for the man of business could be as conveniently at his post from a distance of several miles, as he is now from an adjoining street. The present heavy charges for bringing distant produce to market being nearly saved, the buyer every where would purchase cheaper, and the producer would be still better remunerated. In a word, such a change would be effected as if by magic the whole of



Britain had been compressed into a circle of a few miles in diameter, yet without any part losing aught of its magnitude or beauties.—All this may appear visionary ; but it is less so than seventy years ago it would have been to anticipate much of what, in respect to travelling, has really come to pass,—as, that the common time of passing from London to Edinburgh would be forty-six hours. At the recent opening (in 1825) of the road near Darlington, a train of loaded carriages were dragged by one little steam-engine a distance of twenty-five miles within two hours ; and in some parts of the journey the speed was more than twenty miles an hour : the load was equal to a regiment of soldiers, and the coal expended was not of the value of a crown. An island with such roads would be an impregnable fortress ; for in less time than an enemy would require to disembark on any part of the coast, the forces of the country might be concentrated to defend it.

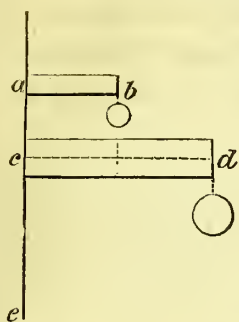
*“ Strength depends on the magnitude, form, and position of bodies, as well as on the degree of cohesion in the material.”* (Read the Analysis, page 125.)

The minute details connected with this branch of the subject belong to the practical engineer, but there are some of the general truths which should be familiar to every body.

*Of similar bodies the largest is proportionally the weakest.*

Suppose two blocks of stone left projecting





from a hewn rock, of which blocks one, as *d*, is twice as long and deep and broad as the other, *b*. The larger one will by no means support at its end as much more weight than the smaller, as its mass is greater, and for two reasons. 1st. In the larger, each particle of the surface of attachment at *c*, in helping to bear the weight of the block itself, has to support by its cohesion twice as many particles beyond it in the double extent of projection, as a particle has to support in the shorter block at *a*; and 2dly, both the additional substance, and any thing appended at its outer extremity, are acting with a double lever advantage to break it, that is, to destroy the cohesion at *c*. Hence, if any such mass be made to project very far, it will be broken off, or will fall by its own weight alone. And what is thus true of a block supported at one end is equally true of a block supported at both ends, and indeed of all masses, however supported, and of whatever forms, if they have projecting parts. It is to be observed also that masses, like an absolutely perpendicular cliff, which have no projecting or overhanging parts, are still limited as to size by the degree of cohesive force among their particles, for the upper part of such a mass tends to crush or break down the lower. A lofty pillar cannot be formed of soft clay.

That a large body, therefore, may have proportionate strength to a smaller, it must be still thicker

and more clumsy than it is longer : and beyond a certain limit no proportions whatever will keep it together, in opposition merely to the force of its own weight.

This great truth limits the size and modifies the shape of most productions of nature and of art ; —of hills, trees, animals, architectural or mechanical structures, &c.

*Hills.* Very strong or cohesive material may constitute hills of sublime elevation, with very projecting cliffs and very lofty perpendicular precipices ; and such accordingly are seen where the hard granite protrudes from the bowels of the earth, as in the Andes of America, the Alps of Europe, the Himalayas of Asia, and the Mountains of the Moon in Central Africa. But material of inferior strength exhibits more humble risings and more rounded surfaces. The gradation is so striking and constant, from granite mountains, down to those of chalk or gravel or sand, that the geologist can often tell the substance of which a hill is composed by observing the peculiarities of its shape.

Even in granite itself, which is the strongest of rocks, there is a limit to height and projection ; and if an instance of either, much more remarkable than now remains on earth, were by any chance to be produced again, the law which we are considering would prune the monstrosity. The grotesque figures of rocks and mountains seen in the paintings of the Chinese,—or actually formed in miniature for their gardens, to express their no-

tions of perfect sublimity and beauty,—are caricatures of nature for which originals can never have existed. Some of the smaller islands in the Eastern Ocean, however, and some of the mountains of the chains seen in the voyage towards China, along the coasts of Borneo and Palawan, exhibit perhaps the very limits of possibility in singular shapes. In the moon, where the weight or gravity of bodies is less than on earth, on account of her smaller size, mountains of a given material might be many times higher than on earth—and observation proves that the lunar mountains are in fact very high.

By the action of winds, rains, currents, and frost, upon the mineral masses around us, there is unceasingly going on an undermining and wasting of supports, so that every now and then immense rocks, or almost hills, are torn by gravity from the station which they have held since the earth received its present form, and fall in obedience to the law now explained.

*The size of vegetables*, of course, is obedient to the same law. We have no trees reaching a height of three hundred feet, even when perfectly perpendicular, and sheltered in forests that have been unmolested from the beginning of time: and oblique or horizontal branches are kept within comparatively narrow limits by the great strength required to support them. The truth, that to have proper strength the breadth or diameter of bodies must increase more quickly than the length, is well illustrated by the contrast existing between the delicate and slender proportions of a young oak or

elm, yet in the seedsman's nursery, and the sturdy form of one which has braved for centuries all the winds of heaven, and has become the monarch of the park or forest.

*Animals* furnish other interesting illustrations of this law.

How massive and clumsy are the limbs of the elephant, the rhinoceros, the heavy ox, compared with the slender forms of the stag, antelope, and greyhound ! And unless the bones were made of stronger material than now, an animal much larger than the elephant would fall to pieces owing to its weight alone. The whale is the largest of animals, but feels not its enormous weight, because lying constantly in the liquid support of the ocean. A cat may fall with impunity from a greater height than would suffice to dash the bones of an elephant or ox to pieces.

For the reason which we are now considering, the giants of the heathen mythology could not have existed upon this earth ; although on our moon, where, as already stated, weight is much less, such beings might be. In the planet Jupiter again, which is many times larger than the earth, an ordinary man from hence would be carrying in the simple weight of his body, a load sufficient to crush the limbs which supported him. The phrase *a little compact man*, points to the fact that such a person is stronger in proportion to his size than a taller man.

The same law limits the height and breadth of architectural structures. In the houses of fourteen stories, which formerly stood for protection, close



under the castle of Edinburgh, there was danger of the superincumbent wall crushing the foundation.

*Roofs.* Westminster Hall approaches the limit of width that is possible without either very inconvenient proportions or central supports; and the dome of the church of St. Peter in Rome is in the same predicament.

*Arches of a bridge.* A stone arch, much larger than those of the magnificent bridges in London, would be in danger of crushing or splintering its material.

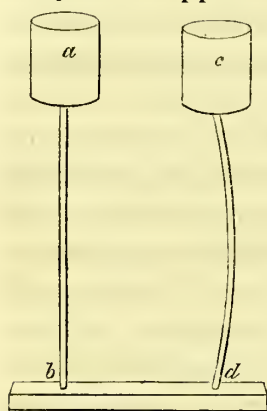
*Ships.* The ribs or timbers of a boat have scarcely a hundredth part of the bulk of the timbers of a ship only ten times longer than the boat. A ship's yard of ninety feet contains perhaps twenty times as much wood as a yard of thirty feet, and even then is not so strong in proportion. If ten men may do the work of a three-hundred-ton ship, many more than three times that number will be required to manage a ship three times as large. Very large ships, such as the two built in Canada, in the year 1825, which carried each nearly ten thousand tons of timber, are weak from their size alone; and the loss of these two first specimens of gigantic magnitude will not encourage to the building of others.

The degree in which the strength of structures is dependent on the *form* and *position* of their parts, will be illustrated by considering the two cases of *longitudinal* and *transverse* compression. And the rule for giving strength to any struc-



ture will be found to be, to cause the force tending to destroy it, to act, as equally as possible, on the *whole* resisting mass at once, and with as little mechanical advantage as possible.

In *longitudinal compression*, as produced by a body *a*, on the atoms of the support *b*, the weight, while the support remains straight, can only destroy the support, by crushing it in opposition

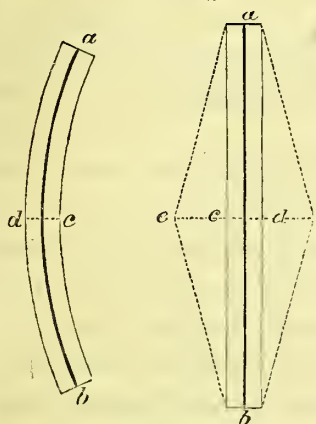


to the repulsion and impenetrability of all of its atoms. Hence a very small pillar, if kept perfectly straight, supports a very great weight; but a pillar originally crooked, or beginning to bend, resists with only part of its strength; for, as seen in *c d*, the whole weight above is supported chiefly on the atoms of the

concave side, which are therefore in greater danger of being oppressed and crushed, while those on the convex side, separated from their natural help-mates, are in the opposite danger of being torn asunder. The atoms near the centre in such a case are almost neutral, and might be absent without the strength of the pillar being much lessened.

Long pillars or supports are weaker than short pillars of the same diameter, because they are more easily bent; and they are more easily bent because a very inconsiderable, and therefore easily effected yielding between each adjoining two of their many atoms, makes a considerable bend in

the whole ; while in a very short pillar there cannot be much bending without a great change in the relation of proximate atoms, and such as can



be effected only by great force. The weight resting on any pillar, and bending it, may be considered as acting (with obliquity dependent on the degree of bending) at the end of a long lever which reaches from the extremity to the centre of the pillar, against the

strength resisting always directly at a short lever reaching from the side *d* to the centre : the strength of the pillar, therefore, has relation to the difference between these levers and to the degree of bending. Shortness then, or any stay or projection, as *a e b*, which, by making the resisting lever longer, opposes bending, really increases the strength of a pillar.

A column with ridges projecting from it, is on this account stronger than one that is perfectly smooth.

A hollow tube of metal is stronger than the same quantity of metal as a solid rod, because its substance standing farther from the centre resists bending with a longer lever. Hence pillars of cast-iron are generally made hollow, that they may have strength with as little metal as possible.

In the most perfect weighing-beams for delicate purposes, that there may be the least possible

weight with the required strength, the arms, instead of being of solid metal, are hollow cones, of which the substance is not much thicker than writing paper.

Masts and yards for ships have been made hollow in accordance with the same principle.

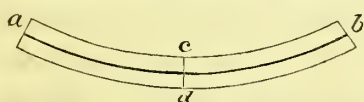
In Nature's works we have to admire numerous illustrations of the same kind.

The stems of many vegetables, instead of being round externally, are ribbed or angular and fluted, that they may have strength to resist bending. Many also are hollow, as corn-stalks, the elder, the bamboo of tropical climates, &c., thereby combining lightness with their strength.—A person who has visited the countries where the bamboo grows, cannot but admire the almost endless uses to the inhabitants, which its straightness, lightness, and hollowness, fit it to serve. Being found of all sizes, it has merely to be cut into pieces of the lengths required for any purpose, and Nature has already been the turner, and the polisher, and the borer, &c. In many of the Eastern Islands it is the chief material, both of the dwellings, and of the furniture; there are the bamboo huts and bungalows, and then the fanciful chairs, couches, beds, &c.; flutes and other wind instruments there, are merely pieces of the reed with holes bored at the requisite distances; conduits for water are pipes of bamboo; bottles and casks for preserving liquids are single joints of larger bamboo with the natural partitions remaining; and bamboo split into threads is twisted into rope, &c.

From the animal kingdom also we have illustrations of our present subject :—as in the hollow stiffness of the quills of birds ; the hollow bones of birds ; the bones of animals generally—strong and hard, and often angular externally, with light cellular texture within, &c.

*Transverse Pressure.*

When a horizontal beam is supported at its extremities, as at *a* and *b*, its weight bends its middle down more or less, as here shewn, the particles on the upper side being compressed, while the parts below are distended ; and the bending and tendency to break are greater, according as the beam is longer and its thickness or depth is less.



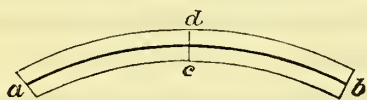
The danger of breaking, in a beam so situated, is judged of, by considering the destroying force as acting by a long lever reaching from an end of the beam to the centre, and the resisting force or strength as acting only by a short lever from the side *d* to the centre ; while only a little of the substance of the beam on the under side is allowed to resist at all. This last circumstance is so remarkable, that the scratch of a pin on the under side of a plank resting as here supposed, will sometimes suffice to begin the fracture.

Because the resisting lever is small in proportion as the beam is thinner, a plank bends and breaks more readily than a beam, and a beam resting on its side bears less weight than if resting on its edge. Where a single beam cannot be



found deep or broad enough to have the strength required in any particular case, as for supporting the roof of a house, several beams are joined together, and in a great variety of ways, as is seen in house-rafters, &c. which, although consisting of three or more pieces, may be considered as one very broad beam, with those parts cut out which would contribute least to the strength.

*The arched form*, resting against immoveable abutments, bears transverse pressure so admirably, because by means of it the force that would destroy, is made to compress, not one side only, but all the atoms or parts of both sides, nearly in the same degree. By comparing this figure with the last, we see that the atoms on the under side of



an arch, must be compressed about as much as those on the

upper side, and are therefore in no danger of being torn, or overcome separately. The whole substance of the arch therefore resists, nearly like that of a straight pillar under a weight, and is nearly as strong.

An error, which has been frequently committed by bridge-builders, is the neglecting to consider sufficiently the effect of the horizontal thrust of the arch on its piers. Each arch is an engine of oblique force (see page 182), pushing the pier away from it. In some instances, one arch of a bridge falling, has allowed the adjoining piers to be pushed down towards it, by the thrust, no longer balanced, of the arches beyond, and the whole structure has given way at once like a child's house or bridge built of cards.



It is not known at what time the arch was invented, but it was in comparatively modern times. The hint may have been taken from nature, for there are instances in alpine countries of natural arches, where rocks have fallen between rocks, and have there been arrested and suspended, or where burrowing water has at last formed a wide passage under masses of rock, and has left them balanced among themselves as an arch above the stream. Nothing can surpass the strength and beauty of some modern stone bridges ;—those for instance which span the Thames as it winds through London.

Iron bridges have been made with arches twice as large as those of stone ; the material being more tenacious and easily moulded, is calculated to form a lighter whole. The bridge of three fine arches lately built between the city of London and Southwark, is a noble specimen, and compared with those erected in the preceding century, appears almost a fairy structure of lightness and grace.

The great domes of churches, as those of St. Peter's in Rome and St. Paul's in London, have strength on the same principle as simple arches. They are in general strongly bound at the bottom with chains and iron-bars, to aid the masonry in counteracting the horizontal thrust of the superstructure.

The Gothic arch is a pointed arch, and is calculated to bear the chief weight on its summit or key-stone. Its use, therefore, is not properly to span rivers as a bridge, but to enter into the composition of varied pieces of architecture. With

what effect it does this, is seen in the truly sublime Gothic structures which still adorn so many parts of Europe.

The following are instances, in smaller bodies, of strength obtained by the arched form.—A thin watch-glass bears a very hard push ;—a dished or arched wheel for a carriage is many times stronger to resist all kinds of shocks than a perfectly flat wheel ;—a full cask may fall with impunity, where a strong square box would be dashed to pieces ;—a very thin globular flask or glass, corked and sent down many fathoms into the sea, will resist the pressure of water around it, where a square bottle, with sides of almost any thickness, would be crushed to pieces.

We have, from the animal frame, an illustration of the arched form giving strength, in the cranium or skull, and particularly in the skull of man, which is the largest in proportion to its thickness :—the brain required the most perfect security, and in the arched form of the skull has obtained it with little weight.—The common egg-shell is another example of the same class : what hard blows of the spoon or knife are often required to penetrate this wonderful defence of a dormant life ! The weakness of a similar substance not arched, is seen in a scale from a piece of freestone so readily crumbling between the fingers.

To determine, for particular cases, the best forms and positions of beams and joists, and of arches, domes, &c., is the business of strict calculation, and belongs therefore to mathematics, or the *science of measures*.

It was a beautiful problem of this kind, which Mr. Smeaton, the English engineer, solved so perfectly, in the construction of the far-famed Eddystone lighthouse. He had to determine the form and dimensions of a building, which should stand firm on a sunken rock, in the channel of a swift ocean tide, and exposed to the fury of tempests from every quarter. Only the man who has himself been driven before the irresistible storm in the darkness of night, and in the midst of dangers, and whose eyes have watched the steady ray from the lighthouse which saved him, can appreciate fully the importance of the studies which bring such useful results ; or can feel how happy he is to have fellow-men, whose talents, although exerted possibly with a view to individual good, are yet, by God's providence, made to accomplish the most philanthropic ends, binding the whole of human kind into one great society of helping brotherhood.

## ANIMAL AND MEDICAL MECHANICS.

*Mechanism of the Human Skeleton.\**

HAVING now completed our study of general mechanics, we shall proceed, with the light thence derived, to examine that most interesting illustration of many of the truths—the solid frame-work of the human body—a perfect work of an unerring Engineer!

There is scarcely a part of the animal body, or an action which it performs, or an accident that can befall it, or a piece of professional assistance which can be given to it, that does not furnish illustration of some truth of natural philosophy; but were we here to enter into much detail, we should be giving minute lessons in medical science, instead of explaining general laws. We shall therefore only touch upon as many particulars as will make the understanding of all the others easy; trying to include among our illustrations, such matters of importance as would be likely to escape the notice of a hasty student.

The *cranium* or *skull* has been already mentioned as an instance of the arched form answering the purpose of giving strength. The brain, in

\* An engraving of the skeleton is given at the end of the volume.

its nature, is so tender or susceptible of injury, that slight local pressure disturbs its action. Hence a solid covering like the skull was required, with those parts made stronger and thicker which are most exposed to injury. An architectural dome is constructed to resist one kind of force only, always acting in one direction, *viz.* gravity; and therefore its strength increases regularly towards the bottom, where the weight and horizontal thrust of the whole are to be resisted; but in the skull, as in a barrel or egg-shell, the mere tenacity of the substance is many times greater than sufficient to resist gravity, and therefore the form and securities are calculated to resist forces of other kinds operating in all directions. When we reflect on the strength displayed by the arched film of an egg-shell, we need not wonder at the severity of blows which the cranium can withstand.

In the early fetal state, that which afterwards becomes the strong bony case of the brain, exists only as a tough flexible membrane. Ossification commences in this membrane long before birth, at a certain number of points from which it spreads, and the portions of the skull formed around these points soon acquire the appearance of so many scales or shells applied on the surface of the brain, and held together by the remaining membrane not yet ossified. They afterwards become firmly fixed together, by projections of bone from each, shooting in among similar projections of the adjoining ones, until all mutually cohere by perfect dove-tailed joints, like the work of a carpenter. These joints are called the sutures of



the cranium, and are visible to extreme old age. Through early childhood, the cranium remains to a certain degree yielding and elastic, causing the falls and blows, so frequent during the lessons of walking, &c. to be borne with comparative impunity. The mature skull consists of two *layers* or *tables*, with a soft *diploe* between them; the outer table being very tough, with its parts dovetailed into each other as tough wood is joined by human artificers; while the inner table is harder and more brittle (hence called *vitreous*), with its edges merely lying in contact.

A very severe partial blow on the skull generally fractures and depresses the part, as a pistol-bullet would: while one less severe, but with more extended contact, being slowly resisted by the arched form, often injures the skull by what is correspondent to the *horizontal thrust* in a bridge, and causes a crack at a distance from the place struck, —generally half-way round to the opposite side. The French in speaking of this effect use the term *contre-coup*. Sometimes in a fall with the head foremost, the skull would escape injury, but for the trunk which falls upon it, and drives the end of the spine against or even through its base.

*In the lower jaw* we have to remark the greater mechanical advantage, or lever-power, with which the muscles act, than in other parts of animals. The temporal and masseter muscles pull almost *directly*, or at right angles to the line of the jaw, while in most other cases, as in that of the deltoid muscle lifting the arm, the muscles act very *obliquely*, and with power diminished in proportion

to the obliquity. An object placed between the back teeth is compressed with the whole direct power of the strong muscles of the jaw. Hence the human jaw can crush a body which offers great resistance, and the jaws of the lion, tiger, shark, and crocodile, &c. are stronger still.

The *teeth* rank high among those parts of the animal body, which appear almost as if they were severally the results of distinct miraculous agencies—so difficult is it to suppose a few simple laws of life capable of producing the variety of form and fitness which they exhibit. They constitute a beautiful set of chisels and wedges, so arranged as to be most efficient for cutting and tearing and grinding the food, with their exterior enamel so hard, that few substances in nature can make an impression upon it. In early states of society, teeth were used for many purposes for which steel is used now. It seems, however, as if the laws of life, astonishing to human intellect as they are, had still been inadequate to cause teeth cased in their hard and polished enamel, to grow as the softer bones grow; and hence has arisen a provision more extraordinary still. A set of small teeth appear soon after birth, and serve the child until six or seven years of age: these then fall out, and are replaced by larger ones, which endure for life; the number of the latter, however, being completed only when the man or woman is full grown, by the four teeth, called wisdom teeth, from coming with the person's maturity, to fill up the then spacious jaw.

*The spine or back bone*, in its structure, has as

much of beautiful and varied mechanism as any part of our wonderful frame. It is the central pillar of support and great connecting chain of all the other parts; and has, at the same time, the office of containing within itself, and of protecting from external injury, a prolongation of the brain, called the spinal marrow, more important to animal life than the greater part of the brain itself. It has united in it the apparent incompatibilities of great elasticity, great flexibility in all directions, and great strength, both to support a load and to defend its important contents,—as we shall now perceive.

*Elasticity.*—The head rests on the elastic column of the spine, as softly as the body of a carriage rests upon its springs. Between each two of the twenty-four vertebræ or distinct bones of which the spine consists, there is a soft elastic *inter-vertebral substance*, about half as bulky as a vertebra, and which yields readily to any sudden jar: then the spine is waved or bent like an italic *f*, as is perceived on viewing it sideways, or in profile, and by this reason, also, it yields to any sudden pressure operating against either end. The bending might seem a defect in a column intended to support weight, but the disposition of the muscles around is such as to leave all the elasticity of that form, and a roomy thorax, without any diminution of strength.

*Flexibility.*—The spine has been compared to a chain, because it consists of many distinct pieces (twenty-four). They are in contact by smooth rubbing surfaces, which allow of a degree of mo-

tion in all directions; and a little motion comparatively between each two adjoining pieces, becomes a great extent of motion in the whole line.

The *strength*—of the spine as a whole, is shewn in the fact of a man's easily carrying upon his head or back a weight heavier than himself; and the strength of each separate vertebra surrounding the spinal marrow, is evident in its being a double arch, or strong irregular ring. The spine increases in size towards the bottom, in the justest proportion, as it has more weight to bear. The articulating surfaces of the spine are so many, and so exactly fitted to each other, and are connected by such number and strength of ligaments, that the combination of pieces becomes, in reference to motion, a much stronger column than a single bone of the same size would be.

Considering the great number of parts forming the spine, and their nice mutual adaptation, it might be expected that injuries and diseases of the structure would be very frequent. The reverse, however, under natural circumstances, is true; so that while hundreds and thousands of works have been published on the diseases of almost every other part of the body, hardly any have been written on spine-affections, and what have appeared are of very recent date. One reason of this is, that whatever regards health and disease is now much more completely analyzed than formerly; but another and the chief reason is, that from a change in modern times introduced into the system of education for young ladies, a consider-



able proportion of them have grown to womanhood with weakened and crooked spines.—The subject merits farther consideration here.

To the well-being of the higher classes of animals, a certain degree of exercise of their various parts is not less necessary than their nourishment, and if, during the period of growth, such exercise be withheld by any cause, the body never acquires its due proportions and strength. To prompt young creatures to the required exertion, nature has given them an overflow of life and energy, as evinced in the ever-changing occupation of a child, in the quick succession of its ideas, in its jumping and skipping, and using all the modes of round-about action to expend muscular energy, instead of seeking, as in after-life, to accomplish its ends in the shortest ways;—and as seen among the inferior animals, in the play of kittens, puppies, lambs, &c. But, strongly as nature has thus expressed herself, tyrant fashion, with a usual perversion of common sense, had of late times, in England, for young women of the higher classes, formed a school discipline, directly at war with nature's dictate; so that a stranger arriving from China, might almost suppose it our design to make crooked and weak spines by that discipline, as it is the design in China to make little feet by the iron shoe. The result is the more striking, when the brothers of the female victims, and who of course have similar constitutions, are seen to be robust, healthy, and well-formed. A *peasant-girl*, when her spirits are buoyant, is allowed to obey her natural feeling, and at proper times to dance,



and skip, and run, until healthy exhaustion asks that repose which is equally allowed; and thus she grows up strong and straight: but the *young lady* is receiving constant admonition to curb all propensity to such vulgar activity, and often, just in proportion as she subdues nature, she receives the praise of being *well-bred*. The multifarious studies, also, of the latter come powerfully in aid of the admonition, by fixing her for many hours every day to sedentary employment; and the consequences soon follow, of weakness in the body generally from the want of the natural quantity and variety of muscular exertion, but weakness of the back particularly, from the manner in which the sitting is usually performed. It would be accounted great cruelty to make a delicate girl stand all day, because her legs would tire, but this very cruelty is in almost constant operation against her back, as if backs could not tire as well as legs. When she is allowed to sit down because she has been long standing, great care is taken that the muscles of the back, which still remain in action as she sits, shall not be at all relieved; for, from the idea that it is ungraceful to loll, she is either put upon a stool which has no back at all, or upon a very narrow chair with a perpendicular back. Now neither of these seats relieves her spine, the stool, however, being less hurtful than the chair, because it allows the spine to bend in different ways, so as to rest the different sets of muscles alternately, while the chair keeps the spine constantly upright and nearly unmoved. This excessive fatigue soon causes the spine, somewhere,

to give way and to bend, and the curvature often becomes permanent. And as when a bend takes place in one situation, there immediately follows an opposite bend above or below, to keep the centre of gravity of the body always directly over the base, the curve thus becomes double, like an italic *f*, and the distortion is rendered complete.—In bending, the spine is sometimes also partially rotated or twisted, so as to shew from behind that waving profile which should be seen only from the side.

When owing to such discipline the inclination of the back has once been begun, it is often rapidly increased by the means used to correct it. Strong stiff stays are put on to support the back, as is said, but which in reality, by superseding the action of the muscles placed there by nature as the supports, cause these to lose their strength, and to be unable, when the stays are withdrawn, to support the body. Longer sittings in the narrow upright chair are then recommended, and sometimes the back is forcibly stretched by pullies, or the patient is kept all day and night lying on an inclined board, losing her health, &c. :—the only things guarded against being, that the patient should take due exercise and air, and should rest properly when she is not taking exercise. With many persons the prejudice had at last grown up, that strong stays should be put on at a very early age, to prevent the first approach of the mischief, and that children should always be made to sit on straight-backed chairs, or to lie on hard planes: and it is probable, that if these cures and preven-

tives had been adopted as universally and strictly as many deemed them necessary, we should now scarcely have in England a young lady of healthful form. What would be said of the person who should try to improve the strength and shape of a young race-horse or greyhound, by binding tight splints or stays round its beautiful young body, and then tying it up in a stall ! But this is the kind of absurdity and cruelty which has been so commonly practised in this country towards beings than whom, as nature offers them, the universe surely contains none more faultless.

A pernicious prejudice, with respect to such curvature or distortion of the spine, long existed, namely, that it was a scrofulous affection ; and many mothers concealed it as much as possible, and sought remedy from quacks far from home. In consequence, until within a few years, the management of spine-diseases was chiefly in the hands of some irregular members of the profession, —and a rich source of wealth it became to them, from many of their remedies being calculated rather to prolong than to cure the evil. The practice in such cases, however, has now fallen into the hands of the profession generally, and science having detected the true cause of the evil, its frequency is already diminished. It has been shewn that to prevent the disease is easy, and that the best cures are those conducted on the general principles of improving the health of the patient by fit regimen, of prescribing such exercises as may directly strengthen the affected part, and of causing the patient when reposing to assume po-

sitions which directly counteract the morbid tendency.

Some might expect here a long description of machines employed in the treatment of spine affections : but the list of those which are useful or safe is very short :—a sofa to rest upon during the day and a fit bed for the night (the “ hydrostatic bed,” proposed by the author of this work, and described in the next chapter, has certain advantages); choice of pleasant means of taking exercise, such as the skipping-rope, shuttlecock, dumbbells, a rope-ladder to climb, a winch to turn, &c. : —and, where it is much desired that the young lady should employ herself in the sitting attitude, as in practising music, a chair may be used, with crutches rising from its side, or with straps descending from pulleys in an overhanging canopy or crane, and kept tight by proper weights at their distant ends, to support the head and shoulders. The author has had a small crane of wood made, which well answers the last-mentioned purpose, and may be attached to a common chair. It would be out of place here to detail those particulars of constitutional treatment, which in peculiar habits may be required to aid the effects of the means above described.

*The ribs.*—Attached to twelve vertebræ in the middle of the back, there are the ribs or bony stretchers of the cavity of the chest, constituting a structure which solves, in the most perfect manner, the difficult mechanical problem of making a cavity with solid exterior, which shall yet be capable of dilating and contracting itself. Each



pair of corresponding ribs may be considered as constituting a hoop, which hangs obliquely down from the place of attachment behind, so that when the forepart of all the hoops is lifted by the muscles, the cavity of the chest is enlarged.

We have to remark the double connexion of the rib behind, first to the bodies of two adjoining vertebræ, and then to a process or projection from the lower, thus effecting a very steady joint, and yet leaving the necessary freedom of motion ; and we observe the forepart of the rib to be joined to the breast-bone by flexible cartilage, which allows the degree of motion required there, without the complexity of a joint, and admirably guards, by its elasticity, against the effects of sudden blows or shocks.

The muscles which have their origin on the ribs and their insertion into the bones of the arm, afford us an example worth remembering of action and re-action being equal and contrary. When the ribs are fixed, these muscles move the arm ; and when the arm is fixed, as by resting on a chair or other object, they with equal force move the ribs. The latter occurrence is seen in fits of asthma and dyspnea.

The human skeleton with its naked ribs, is so associated in the common mind with ideas of death and loss of friends, and all the terrors of doubtful futurity, that to most persons it is an object of abhorrence ; but to the philosophic mind, which rises superior to place and time, the so admirable adaptation of all the parts to their purposes, and of parts which being purely mechanical



are perfectly understood, makes it, independently of all professional considerations, an object of the most intense interest. Such mechanism reveals, by intelligible signs, the hand of the Creator; and a man may be said sublimely to commune with his Maker, who contemplates and understands the structure aright.

The *shoulder-joint* is remarkable for combining great extent of motion with great strength. The round head of the shoulder-bone, that it may turn freely in all ways, rests upon a shallow cavity or socket in the shoulder-blade; and the danger of dislocation from this shallowness is guarded against by two strong bony projections above and behind. To increase the range of motion to the greatest possible degree, the bone called the shoulder-blade, which contains the socket of the arm, slides about itself upon the convex exterior of the chest, having its motion limited in certain directions by its connexion, through the collar-bone or clavicle, with the sternum.

The *scapula* or *blade-bone* is extraordinary as an illustration of the mechanical rules for combining lightness with strength. It has the strength of the arch from being a little concave, like the dished wheel already described, and its substance is chiefly collected in its borders and spines, with thin plates between, as the strength of a wheel is collected in its rim, and spokes, and nave.

The bones of the arms, considered as levers, have the muscles which move them attached very near to the fulcra, and very obliquely, so that the muscles, from working through a short distance

comparatively with the displacement of the resistances at the extremities, require to be of great strength. It has been calculated that the muscles of the shoulder-joint, in the exertion of lifting a man upon the hand, pull with a force of two thousand pounds.

Notwithstanding all the securities to the shoulder-joint now described, in the infinite variety of twists, and falls, and accidents to which men in the busy scene of society are liable, the joint is frequently dislocated, that is, the rounded head of the humerus or arm-bone slips from its socket, with instant lameness as a consequence.

In the treatment of dislocations and fractures of the frame-work of the human body, the surgeon cannot avoid displaying strikingly either his professional skill or ignorance. With what ease does the displaced arm or thigh-bone return to its socket, under the guidance of the skilful hand! and to what horrible, and often unavailing torture, is the patient subjected, when in such a case ignorance dares to act! It is very painful to allow the imagination to dwell upon the records of ancient surgery, and to be made present, as it were, to the stretching of patients on the rack with pulleys and powerful engines, to do what better information could have accomplished with such gentleness. And would that the records of modern times contained no instances of individuals crippled for life by bad practice. To a practitioner in this branch, impunity and a quiet conscience can now be secured only by his having a perfect knowledge of

anatomy, and familiarity with the laws of mechanical philosophy.

With our present information on these subjects, we are surprised at the detail of the practices and errors promulgated in former times, owing to imperfect knowledge of mechanics, even by authors of the highest credit. It would hardly be believed that so distinguished an ornament of English surgery as Mr. Pott, should assign as one reason for not pulling by the hand or foot, in reducing a dislocation of the shoulder or hip, that the intervening joints prevented the strain from reaching the part desired.

Some surgeons, possessing a certain degree of knowledge in mechanics, but only that degree which is dangerous, having heard that the lever was a powerful engine, have tried to replace bones solely by leverage, as it was called. Thus, a man's dislocated arm has been placed over the back of a chair as a fulcrum, or over the top of a door, and while the weight of the suffering body was hanging to it on one side as the resistance, force has been applied to the other side, enough sometimes to break the bone, or to tear away the ligaments and soft parts about the joint.

Other surgeons, after learning in the same way the effects of the pulley, have wished to do all by irresistible extension, and instead of borrowing the moderate assistance which might be useful, have torn muscles and ligaments from their attachments.

It is not the object of this work to enter into an extended examination of the accidents which

befall the body requiring mechanical skill for their proper management, for this would be to deliver a course of instruction on practical surgery ; but it is wished to awaken the attention of the medical student to those valuable general principles which may furnish direction in most difficulties. Knowing these principles, and possessing good sense, he will often be a more effective minister of his art than a man full of learned precedents, who knows them not. To make this lesson more impressive to his young readers, the author may take the liberty of adducing his own experience. When he was himself very young, and had not yet had extensive practical experience, he was thrown into a situation where a heavy medical charge devolved upon him, and where through accidents among a numerous crew, during a very eventful voyage, which led to intercourse with the savage inhabitants of unfrequented coasts, he had, within twenty-six months, more practice in singular wounds, dislocations, and fractures, than falls to the lot of many practitioners during a life :—in that time he became strongly impressed with the importance to the medical man of such knowledge as he now recommends : and he had reason to rejoice that although Natural Philosophy was not then much insisted upon in the course of professional education, circumstances had led him to look carefully at the body through that medium.

*The os humeri*, or bone of the upper arm, is not perfectly cylindrical, but like most of the other bones called cylindrical, it has ridges to give



strength, on the principle explained in the chapter “on strength of materials.”

*The elbow joint* is a correct hinge, and so strongly secured that it is rarely dislocated without fracture.

*The fore arm* consists of two bones with a strong membrane between them. Its great breadth, from this structure, affords abundant space for the origin of the many muscles which go to move the hand and fingers: and the very peculiar mode of connexion of the two bones, gives man that most useful faculty of turning the hand round, into what are called the positions of pronation and supination,—exemplified in the action of twisting, or of turning a gimlet.

The old surgeons, who acted frequently by rules of routine rather than by reasons, in the accident of fracture to one or both bones of the fore arm, often applied a tight bandage, which pulled the bones at the fractured part close to each other, and thus injured the future shape and strength of the arm.

*The wrist.* The many small bones forming the wrist have a signal effect of deadening, in regard to the parts above, the shocks or blows which the hand receives.

*The annular ligament* is a strong band passing round the joint, and keeping all the tendons which pass from the muscles above to the fingers, close to the joint. It answers the purpose of so many fixed pulleys for directing the tendons: without it, they would all, on action, start out like bow-strings, producing deformity and weakness.



*The human hand* is so admirable, from its numerous mechanical and sensitive capabilities, that an opinion at one time prevailed, that man's superior reason depended on his possessing such an instructor and such a servant. Now, although reason, with hoofs instead of fingers, could never have raised man much above the brutes, and probably could not have secured the continued existence of the species,—still the hand is no more than a fit instrument of the godlike mind which directs it.

*The pelvis*, or strong irregular ring of bone on the upper edge of which the spine rests, and from the sides of which the legs spring, forms the centre of the skeleton. A broad bone was wanted here to connect the central column of the spine with the lateral columns of the legs, and a circle was the lightest and strongest. If we attempt still farther to conceive how the circle could be modified so as to fit it—for the spine to rest on, for the thighs to roll in, for muscles to spring from, both above and below, for the person to be able to sit, &c., we shall find, on inspection, that all our anticipations are realized in the most perfect manner. In the pelvis, too, there are the thyroid hole and ischiatic notches, furnishing subordinate instances of contrivance to save material and weight:—they are merely deficiencies of bone where solidity could have given no additional strength. The broad ring of the pelvis protects most securely the important organs placed within it.

*The hip joint* exhibits the perfection of the ball and socket articulation. It allows the foot to

move round in a circle, as well as to have the great range of backward and forward motion, exhibited in the action of walking. When we see the elastic tough smooth cartilage which lines the deep socket of this joint, and the similar glistening covering of the ball or head of the thigh-bone, and the lubricating synovia poured into the cavity by appropriate secretories, and the strong ligaments giving strength all around, we feel how far the most perfect of man's works falls short of the mechanism exhibited in nature.

*The thigh bone* is remarkable for its two projections near the top, called trochanters, to which the moving muscles are fixed, and which lengthen considerably the lever by which the muscles work. The shaft of the bone is not straight, but has a considerable forward curvature. Short-sightedness might suppose this a weakness, the bone being a pillar to support a weight; but the bend gives it in reality the strength of the arch, to bear the action of the mass of muscles called *vastus*, which lies and swells upon its fore part.

*The knee* is a hinge joint of complicated structure, claiming the most attentive study of the surgeon. The rubbing parts are flat and shallow, and therefore the joint has little strength from form; but it derives security from the numerous and singularly strong ligaments which surround it. The ligaments on the inside of the knees resemble, in two circumstances, the annular ligaments of joints, *viz.* in having a constant and great strain to bear, and yet in becoming stronger always as the strain increases. The line of the leg, even in the

most perfect shapes, bends inwards a little at the knee, requiring the support of the ligaments; and in many persons it bends very much; but the inclination does not increase with age. The legs of many weakly in-kneed children become straight by exercise alone. This inclination at the middle joint of the leg, by throwing a certain strain on the ligaments, gives, in such actions as jumping, running, &c., an increase of elasticity to the limb.

In the knee there is a singular provision of loose cartilages between the ends of the bones. They have been called friction-cartilages, from a supposed relation in use to friction-wheels, but their real effect seems to be, to accommodate, in the different positions of the joint, the surfaces of the rubbing bones to each other.

Under the head of *Pneumatics*, we shall find that the bones forming the joints are held together, independently of their ligaments, by a constant pressure of the atmosphere, amounting in the knee, for instance, to upwards of sixty pounds.

The great muscles on the fore-part of the thigh are contracted into a tendon a little above the knee, over and in front of which the tendon has to pass to reach the top of the leg, where its attachment is. The part of the tendon over the joint becomes bony, and forms the patella or knee-pan, often called the pulley of the knee. This peculiarity enables the muscles to act more advantageously, by increasing the distance of the rope from the centre of motion. The patella is moreover a sort of shield or protection to the fore-part of this important joint.

The leg below the knee, like the fore-arm already described, has two bones. They offer spacious surface of origin for the numerous muscles required for the feet, and they form a compound pillar of greater strength than the same quantity of bone as one shaft would have had. The individual bones also are angular instead of round, hence deriving greater power to resist blows, &c.

*The ankle-joint* is a perfect hinge of great strength. There is in front of it an annular ligament, by which the greater part of the tendons passing downwards to the foot and toes are kept in their places. One of these tendons passes behind and under the bony projection of the inner angle, in a smooth appropriate groove, exactly as if a little fixed pulley were there.

*The heel*, by projecting so far backwards, is a lever for those strong muscles to act by, which form the calf of the leg and terminate in the tendo achillis. The muscles, by drawing at it, lift the body, in the actions of standing on the toes, walking, dancing, &c. In the foot of the negro the heel is so long as, in European estimation, to appear ugly; and its great length rendering the effort of smaller muscles sufficient for the various purposes, the calf of the negro's leg is smaller than of other races of men.

In a graceful human step the heel is always raised before the foot is lifted from the ground, as if the foot were part of a wheel rolling forward; and the weight of the body, supported by the muscles of the calf of the leg, as just described, rests for the time on the fore-part of the foot and



toes. There is at that time a bending of the foot in a certain degree. But where strong wooden shoes are used, or any shoe so stiff that it will not yield and allow this bending of the foot, the heel is not raised at all until the whole foot rises with it, so that the muscles of the calf are scarcely used, and in consequence soon dwindle in size, and almost disappear. Many of the English farm servants wear heavy stiff shoes, and in London may constantly be seen as the drivers of country waggons, with fine robust body and arms, but with legs which are fleshless spindles, producing a gait most awkward and unmanly. The brothers of these men, otherwise employed, are not so mis-shapen; and even they themselves, when they choose to become soldiers, and are trained in military exercises, lose their peculiarity. What a pity that, for the sake of a trifling saving, graceful nature should be thus deformed. An example of an opposite kind is seen in Paris, where, as the streets have no side pavements, and the ladies are obliged consequently to walk almost constantly on tiptoe, the great action of the muscles of the calf has given a conformation of the leg and foot, to match which the Parisian belles proudly challenge all the world,—not aware, probably, that it is a defect of their city to which the boasted peculiarity is mainly due.

A person confined to bed for a week or two by sickness, has generally to remark a much greater wasting of the legs than of the arms; the reason of which is, that the muscles of the leg, in ordinary cases, being more in use than those of the arms,



their ordinary bulk is more dependent on use, and they suffer a corresponding change from inaction.

Such facts as now mentioned, bear directly on the subject so near the hearts of many English mothers, *viz.* the weak and crooked backs of their daughters. From such they may understand that strong stays, which in part supersede the action of the muscles placed by nature around the spine to support it, cause these muscles to dwindle, and afterwards, when the support of the stay fails or becomes unequal, leave the back to bend or twist. Stays, therefore, can neither help to make strong and well-formed backs originally, nor can they be a remedy after the weakness has commenced. A healthy young woman from the country, with the spine lying deep between the firm cushions of muscle which support it, if, according to town fashion, braced up in tight stays, will frequently, at the end of a short time, exhibit such a wasting of the flesh, that the points of bone in the spine may be counted by the eye, all the way down.

*The arch of the foot* is to be noticed as another of the many provisions for saving the body from shocks by the elasticity of the supports. The heel, and the ball of the toes, are the two extremes of the elastic arch, and the leg rests between them.

Connected with elasticity, it is interesting to remark how imperfectly a wooden leg answers the purpose of a natural leg. The centre of the body, when supported by the wooden leg, which always remains of the same length, must describe, at each step, a portion of a circle of which the bottom knob of the leg is the centre ; and the body is therefore

constantly rising and falling ;—but with the natural legs, which, by gentle flexure at the knee, are made shorter or longer in different parts of the step as required, the body is carried along in a manner perfectly or nearly level. In like manner, a man riding on horseback, if he keep his back upright and stiff, has his head jolted by every step of the trotting animal ; but the experienced horseman, even without rising in the stirrups, by letting the back yield a little at each movement, as a bent spring yields during the motion of a carriage, can carry his head quite smoothly along.

In a general review of the skeleton, we have to remark, 1st, the nice adaptation of all the parts to one-another, and to the strains which they have respectively to bear ; as—in the size of the spinal vertebræ increasing from above downwards—the bones of the leg being larger than those of the arm, and so on. 2dly, the objects of strength and lightness combined ; as by the hollowness of the long bones—their angular form—their thickening and flexures in particular places where great strain has to be borne—the enlargement of the extremities to which the muscles are attached, lengthening the lever by which these act, &c. 3dly, we have to remark the nature and strength of material in different parts, so admirably adapted to the purposes which the parts serve : there is bone, for instance, in one place nearly as hard as iron, where covered with enamel, it has the form of teeth, with the office of chewing and tearing all kinds of matter used as food ; in the cranium, again, bone is

softer, but tough and resisting ; in the middle of long bones it is compact and little bulky, to leave room for the swelling of the muscles lying there ; while, at either end, with the same quantity of matter, it is large and spongy, to give a broad surface for articulation : and in the spine the bodies of the vertebræ, which rest on an elastic bed of intervertebral substance, are light and spongy, while their articulating surfaces and processes are very hard. In the joints we see the tough elastic smooth substance called cartilage covering the ends of the bones, defending and padding them, and destroying friction. In infants we find all the bones soft or gristly, and therefore calculated to bear with impunity the falls and blows incidental to their age ; and we see certain parts, where elasticity is necessary or useful, remaining cartilage or gristle for life, as at the anterior extremities of the ribs. About the joints we have to remark the ligaments which bind the bones together, possessing a tenacity scarcely equalled in any other known substance ; and we see that the muscular fibres, whose contractions move the bones and thereby the body,—because they would have rendered the limbs clumsy even to deformity had they all passed over the joints to the parts which they have to pull,—attach themselves at convenient distances, to a strong cord called a tendon, by means of which, like a hundred sailors at a rope, they make their effort effective at any distance. The tendons are remarkable for the great strength which resides in their slender forms, and for the lubricated smoothness of their surfaces. Many

other striking particulars might be enumerated, but these may suffice.—Such, then, is the skeleton or general frame-work of the human body; less curious and complicated perhaps than some other parts of the system which we have yet to examine, but so perfect and so wonderful, that the mind which can attentively consider it without emotion, is in a state not to be envied.\*

The living force of man has been used as a working power in various ways, as in turning a winch—pulling at a rope—walking in the inside of a large wheel to move it, as a squirrel or turn-spit dog moves his little wheel, &c. Each of these has some particular advantage; but the mode in which, for many purposes, the greatest effect may be produced, is for the man to carry up to a height his body only, and then to let it work by its weight in descending. A bricklayer's labourer would be less fatigued to lift twice as many bricks to the top of a house in the course of a day, by ascending the ladder without a load and raising bricks of nearly his own weight over a pulley each time in descending, than by carrying fewer bricks and himself up together, and descending again without a load, as is still usually done.

Reflection, independently of experiment, would naturally anticipate the above-stated result, for the

\* In the second and third editions of this work a criticism was introduced at this place of a treatise on “Animal Mechanics,” published as part of the *Library of Useful Knowledge*; in which treatise the author, from imperfect acquaintance with Natural Philosophy, had fallen into many grave errors. That note, having answered its purpose, is not repeated here.



load which a man should be best able to carry, is surely that from which he can never free himself,—the load of his own body. Accordingly the strength of muscles and disposition of parts are all such as to make his body appear very light to him.

The question which was agitated with such warmth some time ago as to the propriety of condemning men and women to work on the tread-mill, receives an easy decision here. They work by climbing on the outside of a large wheel or cylinder, which is turning by their weight, and on which, to avoid falling from their proper situation, they must advance just as fast as it turns. There are, on the outside of the cylinder, projections or steps for the feet, and the action to the workers is exactly that of ascending an acclivity. Now as nature has fitted the human body for climbing hills as well as for walking on plains, the work of the tread-mill, under proper restrictions as to duration, must be nearly as natural and healthful as any other.—Its effects have ultimately proved it to be so.

Animal power being exhausted in proportion as well to the time during which it is acting, as to the intensity of force exerted, there may often be a great saving of power by doing work quickly, although with a little more exertion during the time. Suppose two men of equal weight to ascend the same stair, one of whom takes only a minute to reach the top, and the other takes four minutes, it will cost the first but a little more than a fourth part of the fatigue which it costs the second, because the exhaustion has relation to the time



during which the muscles are acting. The quick mover may have exerted, perhaps, one-twentieth more force in the first instant, to give his body the greater velocity which was afterwards continued, but the sloth supported his load four times as long.

A healthy man will run rapidly up a long stair, and his breathing will scarcely be quickened at the top; but if he walk up slowly, his legs will feel fatigued, and he will have to wait some time before he can speak calmly.

For the same reason coach-horses are much spared by being made to gallop up a short hill, and being then allowed to go more slowly for a little time, so as to rest at the top.

The rapid waste of muscular strength which arises from continued action, is proved by keeping the arm extended horizontally for some time. Few persons can continue the exertion beyond a minute or two. In animals which have long horizontal necks, there is a wonderful provision of nature in a strong elastic substance on the back or upper part of the neck, which nearly supports the head independently of muscular exertion.

In further illustration of the truth that strength is saved in many cases by doing work quickly, we may recall the fact explained at page 93, that a body thrown or shot upwards with double velocity, rises four times as far as when shot with a single velocity, or half of the other.

“ *Instruments.*”

The following remarks regard some instruments

used by medical men, and which range under the present division of "Mechanics."

*The obstetric forceps.*—As the blades beyond the joint or fulcrum are longer than the handles, the pressure on the head included in them is less than that exerted by the hand that uses them, but its degree should always be kept present to the mind of the operator.

*The vectis*, or lever used instead of the forceps just mentioned, is a dangerous instrument in unskilful hands. In fact, whenever it is used as a lever, in the common acceptation of the term, with some part of the pelvis as the fulcrum, the use of it is a piece of unskilful cruelty; for the soft parts between the bone and the instrument are bruised not only with the whole force of the hand, but with twice or thrice as much, according as the resistance is nearer to the fulcrum than to the hand. The instrument is safely used, only when the operator makes one of his hands the fulcrum, and uses the other as the power, or makes different parts of the same hand answer both purposes; and then there is a resemblance between the action of the vectis and of a hook.

The *levator*, or lever for raising the broken and depressed portion of the skull in trepanning, has a fulcrum attached to it by a joint. Care should be taken to place this fulcrum where its pressure cannot be injurious.

The *circular-saw* or *crown-saw* of the trephine, should be worked with a quick motion and gentle pressure, for the reason given at page 176, when treating of cutting instruments. The purpose is

thereby attained, both sooner and better, and the head of the patient is less shaken.

For the same reason, in amputations, a light and quick motion of the straight saw causes less jarring, and effects an easier division of the bone.

In using the amputation knife, the speed, neatness, and success of the operation, are all favoured by blending the drawing or saw motion of the knife, with the pressure towards the bone.

These last observations are of a hundred similar, which might be made to prove the extreme importance to a surgeon of having familiarity with the use of tools or instruments. Perhaps a person cannot better acquire this than by practising, while young, some amusing work of carpentry. Manual dexterity, and a little readiness at mechanical contrivance, so frequently prove of importance to persons in all stations, that it is a great defect in the prevailing systems of general education, not to cultivate them with greater attention.

*The tooth-key* is an instrument found in many hands, and persons who do not pretend to more than the lowest degree of skill in the healing art, are not afraid to use it. The consequence is, that perhaps scarcely a day passes, in which teeth are not broken and jaws splintered, and gums bruised even to sloughing, by the unskilful or awkward use of it. The common tooth-key may be compared to a wheel and axle, the hand of the operator acting on two spokes of the wheel to work it, while the tooth is fixed to the axle by the claw, and is drawn out as the axle turns. The gum and alveolar process of the jaw, form the support on which the axle

rolls. The common errors in tooth-drawing by the key, are these :

1st. Turning the key towards that side, where the adjoining teeth are so close that the tooth to be drawn cannot pass, without either breaking one of them, or being itself broken. Sometimes two, or even three teeth are thus unfixed instead of one.

2d. Neglecting the natural inclination of the tooth. By winding it round in the direction in which it already inclines, and in accordance with a bend which is generally found in it, the operation is easy and safe ; but by drawing it in the opposite way, it not unfrequently is broken, or it splinters the part of the jaw-bone in which it was set.

3d. If the tooth-claw be blunt, its point may slip upon the tooth, so as to produce a jar which is very apt to break the tooth.

4th. Unless the axle or fulcrum of the key be made to rest as evenly as possible on the gum, it will tear or otherwise injure the gum. It should rest, if possible, over the part of the bone in which the tooth is set, for if not—as when a back tooth is drawn by an instrument resting on a part considerably anterior to it—the twist produced is painful, and there is danger of splintering.

A man who, after making these reflections, operates leisurely a few times on the dead subject, will be able to give instant and safe relief to very common and most intense suffering. And it is hardly excusable in any medical man who may be placed where a professed dentist cannot be procured, to neglect acquiring a talent so easy.



Some dentists, by a strong forceps made for the purpose, pull teeth *directly* out ; others by a simple sharp-pointed lever push them out ; and others use a forceps in the manner of the tooth-key, by resting one side of it on the gum as a fulcrum, and then giving it a twisting motion : in the latter case the resting side of the forceps is formed like the bolster of a tooth-key. But much more in all cases depends on the dexterity of the operator than on the form of the instrument.

*Steel trusses for ruptures* are among the blessings to suffering humanity which modern ingenuity has supplied. From the unhealthy employments of some men, and the early dissipation or unnatural modes of life of others, debilitated constitutions are frequent, and are often transmitted to offspring ; and one of the lamentable effects is that weakness of the flesh forming the sides of cavities which, on occasions of strong effort, allows at particular points the living parts to protrude from within, so as to form tumours under the skin. A person perfectly healthy may suffer the same injury from a very violent strain or pressure on the abdomen. The occurrence is called *hernia* or *rupture* : the most common hernia is that of the small intestine through the groins.

Formerly this occurrence disabled for life. A man who had hernia was discharged from the army or navy ; he could not ride on horseback, or take usual exercise ; he could not lift a weight ; and in a word, he often became a miserable burden to himself and others. Now, by fitting the pad of a good steel truss to the part, the rupture is as



perfectly restrained, as if the hand of a skilful surgeon were constantly there. The truss may be put on and off, with as little reflection or trouble, as a part of the ordinary dress, and the man becomes again almost as fit for all the duties of life as if he were without his ailment.

The old and still common form of the steel truss is that of a half or three-quarter hoop, so bent and tempered, that when put upon the patient, one end, which has a pad upon it, presses with a given force, over the opening by which the rupture protrudes, and the remainder tightly embraces the body. The objections to this kind of truss are, the difficulty of making it to fit exactly ; its being rather troublesome to put on and off ; and its pressing disagreeably round the body.

Another kind of truss, free from these objections, consists of a little more than half a hoop, with a pad at each end : one of the pads supports the weakness, and the other rests upon the centre of the back, to bear all the strain there, while the hoop itself passing round the hip farthest from the hernia reposes loosely on the hip. This truss may be called self-adjusting, for it almost of itself falls into its place, and needs no fastenings ; the same truss fits all persons of one size, whatever their shape ; and the strength may be adjusted by changing the number of plates in the spring-hoop.

*Tourniquets, crutches, splints, &c. &c.* are so simple in all respects as not to merit special notice here.

This section contains some of the reflections which, in contemplating the human skeleton, occur

to a person familiar with mechanical philosophy ; and the more complete such a person's knowledge is of anatomy, physiology, surgery, and medicine, the more numerous will be the professional objects on which this philosophy will shed a light dissipating doubt and error. The author has not entered into more minute detail, because it would have been encroaching upon the office of the teachers of particular departments, and because he thinks that any one who is not enabled, by the examples here given, to make the applications of the general laws to all possible cases, may account the study of the healing art unsuited to the faculties with which he is endowed.

## PART III.

## THE PHENOMENA OF FLUIDS.\*

## SECTION I.—HYDROSTATICS.

## ANALYSIS OF THE SECTION.

*The particles in a fluid mass are freely moveable among one-another, so as to yield to the least disturbing force; and if bearing force at all, can be at rest only when equally forced in all directions. Hence:*

1. *In a mass of fluid submitted to compression, the whole is equally affected, and equally in all directions. A given pressure, for instance, made by a plug forced inwards upon a square inch of the surface of a fluid filling a vessel, is suddenly communicated to every square inch of the vessel's surface, however large, and to every inch of the surface of any body immersed in the fluid.*
2. *In any fluid, the particles that are below bear the weight of those that are above, and there is, therefore, within the mass, a pressure increasing exactly with the perpendicular depth, and not influenced by the size, or shape, or position of the containing vessel.*
3. *The open surface of a fluid is level; and if various pipes or vessels communicate with each other, any fluid admitted to them will rise to the same level in all.*
4. *A body immersed in a fluid displaces exactly its own bulk of it, which quantity having been just supported by the fluid around, the body is pressed upward or supported, with a force exactly equal to the weight of the fluid displaced, and must sink or swim according as its own weight is greater or less than this. By comparing therefore the weight of a body with the force which holds it up in a fluid, the comparative weights, or specific gravities, are found.*

\* Read again the Synopsis, page 1.

*“ Fluid.”*

It was explained in Part I. that the same atoms may exist in the form of a solid or of a fluid ; and as a fluid, they may either constitute a dense liquid like water, or a light elastic mass like air. A pound of ice, or a pound of water, or a pound of steam, differ only in the particles being more or less distant from each other, owing to the different quantities of heat among them. In the ice, they are comparatively near, and are held together by attraction, as if they were spitted or glued to each other ; in the water, the repulsion of heat seems nearly to balance attraction, and to leave the particles at liberty to glide about among each other almost without friction ; and in the steam, the repulsion altogether overcomes the attraction, and the particles separate to a great distance, as if held apart by some bulky elastic medium. The few facts not evidently reconcilable with this simple and satisfactory explanation of so many phenomena,—as that water in freezing, and even in cooling down from forty degrees to the freezing point, increases in volume, instead of contracting, like things in general, and like itself in cooling at other temperatures,—and that baked clay, in proportion as it is more heated, contracts instead of dilating,—are treated of in other parts of our work.

Whether matter be in the solid or fluid form, the properties of the individual atoms remain unchanged, that is, the atoms always exist in accordance with the “ general truths ;” but as, in the chapter on Mechanics, we found so many important modifications of effect produced by the



circumstance of the attraction being in the degree which produces solid cohesion among the particles, in this chapter on fluids we shall find as many important results springing from the circumstance of non-cohesion or fluidity.

In a liquid the particles, although comparatively near to one-another, seem not to be in actual contact; for the mass may be condensed indefinitely by pressure. The force required, however, to change the volume of a liquid in any sensible degree, is so great, that until improved means of experiment, recently contrived, liquids were accounted absolutely incompressible. In aeriform fluids, on the contrary, each particle, under common circumstances, has about two thousand times as much space to itself as when forming part of a liquid or solid; and hence it is that these fluids are so extensively compressible and dilatable—or elastic, as they are called. On account of this elasticity, they exhibit so many important phenomena, in addition to those of mere fluidity, that the consideration of them requires to be gone into apart, and forms the branch of the subject called *Pneumatics*, from a Greek word, signifying “spirit” or “breath!”

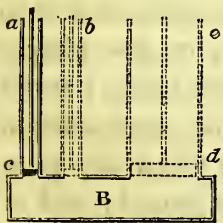
*“In a quantity of fluid submitted to compression, the whole mass is equally affected, and similarly in all directions. A given pressure, therefore, made upon an inch of the surface of a fluid confined in a vessel, as by a plug forced inwards, is suddenly borne by every inch of the surface of the vessel, however large, and by every inch of the surface of any body immersed in the fluid.”*



This truth is of great importance, both from its explaining so many remarkable phenomena of nature, and from the useful applications of it in the construction of machinery.

When a man compresses in his hand a bladder full of air, he readily conceives that the air immediately under his fingers is not at all more compressed, than that in every other part of the bladder; and of course that every part of the bladder's surface must be pressing the air as much as those parts of it on which his fingers rest, and must be bearing a re-action or resistance of the air in an equal degree; and that every single particle of air must be acted upon equally on every side, so that if a small opening were made in the bladder any where, the air would issue from it with equal readiness. This is in accordance with the characteristic of fluidity, "that the particles glide about among one-another almost without friction, so that a particle can never be at rest unless when equally urged in all directions."

In like manner, if a close vessel B be filled with water, and into the top of it a tube *a c* be screwed, and if then, by means of a cork or moveable plug in the tube at *c*, the surface of the water in the vessel be pressed upon with a force of one pound, the water throughout the whole will be squeezed or condensed in proportion to the pressure, and every other portion of the vessel B, of equal surface with *c*, will be keeping up the condensation just as much as *c*, and will be



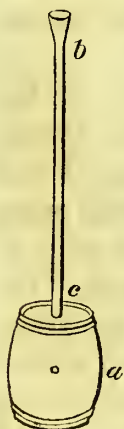
bearing the resistance or elasticity of the water to the extent of one pound. And if there were another similar tube *b*, also with a plug, screwed into the top of the box *B*, the force of one pound depressing the plug *c* would be pushing up the plug *b* with the same force. And if there were many other similar tubes and plugs, by acting on one, all would be equally affected ; and a plug or piston of double size would be twice as much affected as the smaller one ; and a plug *d*, of ten times the size, would be lifted with a force of ten pounds. Hence it appears that, through the medium of confined fluid, a force of one pound, acting upon an inch square of the fluid surface in a vessel, may become a bursting force of ten or a hundred or a thousand pounds, according to the size of the vessel, or may be used as a mechanical power to overcome a force much more intense than itself. It will be explained below that the well-known hydrostatic press is merely a large plug or piston as here described, forced up against the substance to be pressed by the action of a smaller piston in another barrel.

If in the above figure the tube *a* were such as to contain just one pound of water, on the plug *c* being withdrawn from it, and water being poured in to fill it, the same pressure or condensation would take place in the box *B* as when the plug was pressed with the force of one pound ; and of course exactly the same effects would follow on the sides of the vessel and on the other pistons : and if in the other tubes also, water were substituted for the pistons, it is evident that, to effect a balance in all, it would require to stand as high in every

one as in the tube *a c*, producing the same level in all, whatever their size.

The fact, that the weight of one pound of water, or any other force of one pound similarly applied, may be made, through the medium of extended fluid surface, to produce a pressure of hundreds or of thousands of pounds, has been called the “hydrostatic paradox;” yet there is nothing in reality more paradoxical in it than that one pound at the long end of the lever should balance ten pounds at the short end: indeed it is but another means, like the contrivances usually called mechanical powers, and described in the last chapter, of balancing different intensities of force, by applying them to parts of an apparatus moving with different velocities. Here the tube *a* being ten times smaller than the tube *e*, the piston in *a* must descend ten inches to raise the greater piston in *e* one inch.

This law of fluid pressure is rendered very striking in the experiment of bursting a strong cask by the weight or action of a few ounces of water. Suppose a cask *a* already filled with water, and that a long small tube *b c* is screwed tightly into its top, which tube will contain only a few ounces of water; by pouring these few ounces into the tube, the cask will be burst. In explanation, it is unnecessary to say more than that if the tube have an area of a fortieth of an inch, and contain, when filled, half a pound of water, that water would produce a pressure of half a pound upon every fortieth of an inch



all over the interior of the cask, or nearly 2,000lbs. on the square foot,—a pressure greater than a common cask can bear.

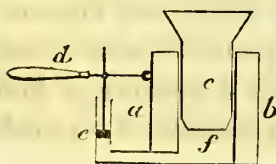
A similar effect is seen in what is called the *hydrostatic bellows*. This consists of a long small



tube *a b*, into which water is poured to enter the body of the apparatus at *c*, which resembles the common bellows, in having wooden boards above and below, and strong leather connecting them. If the tube *a b* holds an ounce of water, and has itself only one-thousandth of the area of the top of the bellows, an ounce of

water in it will balance weights of a thousand ounces placed on the top of the bellows at *d*. If mercury were substituted in this machine for water, the effect would be fourteen times greater, because mercury is fourteen times heavier in the same bulk. And if a man stand on a large bellows of the kind, he may raise himself by blowing into the tube with his mouth.

The annexed cut will give an idea of Mr. Bramah's singularly powerful and useful *hydrostatic* or *hydraulic press*; which, if compared with the bellows, exhibits merely a strong forcing pump instead of the lofty tube, and a barrel with its piston instead of the leather and boards. The



letter *e* points out the piston of the forcing pump worked by the handle *d*, and driving water along the horizontal



tube into the space  $f$  under the large solid piston  $c$ , which last, with its spreading top is urged against the object to be compressed. If the small pump have only one-thousandth of the area of the large barrel, and if a man, by means of its lever-handle  $d$ , press its piston down with a force of five hundred pounds, the piston of the great barrel will rise with a force of one-thousand times five hundred pounds, or more than two hundred tons. Scarcely any resistance can withstand the power of such a press; with it the hand of an infant can break a strong iron bar; and it is used to condense substances, as cotton or hay for sea voyages, to raise great weights, to uproot trees, to tear things asunder, &c.

*The Dilator* is a surgical instrument of extensive applicability, of which the action depends on the principle of the communication of fluid pressure. It was proposed by the author some years ago, and was brought to great practical perfection by his brother, Dr. James Arnott (now superintendant surgeon in the service of the Hon. East-India Company), in whose publication it is minutely treated of. Many professional men in this country doubted of its power, from not being aware of the nature of fluid action; but it is in reality a kind of hydraulic press, allowing the operator to act with the most gentle or most energetic force. Further remarks are made upon it in the medical section which follows this chapter.

“ *In any fluid, the particles that are below bear the weight of those that are above, and there is there-*



*fore a pressure among them increasing in exact proportion to the perpendicular depth, and not influenced by the size, or shape, or position of the containing vessel."*

The atoms of matter having gravity, it is evident that the upper layer of any mass of fluid must be supported by the second, and this with its load by the third, and the third with its double load by the fourth, and so on. This truth is experimentally proved by putting different heights of liquid into an upright tube, of which the bottom is closed by a flap having a spring or lever to support it, and to indicate the force acting on it. And what is true of the entire column of water in the tube, may be considered true of any single line of atoms; just as it would be true of a line of bricks piled one above another.

A tube of which the area is an inch square, holds, in two feet of its length, nearly a pound of water; hence, the general truth, well worth recollecting, that the pressure of water at any depth, whether on the side of a vessel or on its bottom, or on any body immersed, is nearly one pound on the square inch for every two feet of depth.

The striking effects from the increase of pressure in a fluid, at great depths, are of course most commonly exhibited at sea. The following instances will illustrate them.

If a strong square glass bottle, empty, and firmly corked, be sunk in water, its sides are generally crushed inwards by the pressure before it reaches a depth of ten fathoms.

A chamber of air similarly let down with a man

in it, would soon allow him to be drowned by the water bursting in upon him ;—as really happened to an ignorant projector.

When a ship founders in shallow water, the wreck on breaking to pieces generally comes to the surface, and is cast upon the beach ; but when the accident happens in deep water, the great pressure at the bottom forces water into the pores of the wood, and makes it so heavy that no part can ever rise again to reveal her fate.

A bubble of air or of steam, set at liberty far below the surface of water, is small at first, and gradually enlarges as it rises.

A man who dives deep, suffers much from the compression of his chest, as the elastic air within yields under the strong pressure. This limits the depth to which divers can safely go.

It is not known whether there is a limit to the pressure which fishes can bear with impunity, but they are chiefly found living in the shallower waters on coasts, or on banks in the midst of the ocean, such as the banks of Newfoundland, the Dogger-bank, and other fishing stations out at sea. In rounding the Cape of Good Hope, at a considerable distance from land, ships pass over the bank of Lagullas, where a hook let down with a bit of red rag or almost any thing as a bait, immediately secures its cod-fish.

By sending a vessel, prepared for the purpose, down into the deep sea, we can readily prove the compressibility of water. Suppose the vessel to be made with only one entrance, and that a small round opening, into which, instead of a cork, a

sliding rod has been closely fitted. If then, when filled with water, and having the rod inserted into the opening, it be allowed to sink in the sea, the pressure around will push the rod inwards, in a degree proportioned to the yielding or compression of the water within : and if there be on the rod a stiff-sliding ring, or other contrivance to indicate on the return of the vessel how far the rod had been driven inwards, the apparatus will shew the degree of compression at the greatest depth to which it has descended. Water a thousand fathoms below the surface is less bulky by about one-twentieth part than when at the surface.

The following are proofs of the pressure of weight in an open fluid, operating in all directions, as any pressure does in the case of a confined fluid.

A bottle-cork carried far under water, is not flattened as if it were pressed unequally, but is reduced in all its dimensions, so as to appear a phial-cork of the usual form.

If a corked empty bottle be sent down into the sea, the cork is generally forced inwards at a given depth, and equally so in whatever direction the mouth of the bottle may happen to point.

If a vessel containing water have an opening in the side, covered by a valve or flap so contrived as to tell the force required to keep it shut, we find that the water tends to escape just as powerfully through such an opening as it would through one in the bottom, with the same elevation of water over its centre. And different equal openings in

the side of a vessel require to be closed with forces exactly proportioned to the heights of liquid above their centres.

In an open square-sided vessel full of water, the whole pressure on any upright side is just half the pressure on an equal extent of horizontal bottom; for the centre of the side being just half as deep as the bottom, the pressure on any point there is only half as great as on a point at the bottom, and on points above the level of the centre is just as much less than half, as, at corresponding distances below, it is more than half, and so it amounts to an exact half in the whole. Considering that the pressure on every point below the central level is greater than on every point above it, we see the reason why, to support a sluice or flood-gate by a single stay on the outside, the point at which the pressure has to be made is below the central level. Calculation discovers that this point, called the centre of pressure, is at one-third from the bottom. The knowledge of such facts furnishes rules for the construction of large vessels for liquids, canal embankments, &c.

The pressure on a given extent of the side of a narrow vessel is just as great as on the same extent of the side of a wide vessel, having the same depth of fluid: because, as now explained, it depends entirely on the extent of surface acted upon and the depth of liquid.

Hence a flood-gate or sluice which shuts out the ocean, as in docks opening to the sea, bears no more pressure than if it stood only against an equal depth of lake or river; or than if it were



one of two such flood-gates become the sides of a very narrow vessel, made to contain only a few hogsheads of water.

Hence again, the fear is unfounded which has been expressed, with reference to the formation of a canal between the Red Sea and the Mediterranean,—that because the former, owing to the effect of easterly winds at its mouth, &c., is twenty feet higher than the latter, it might burst through the flood-gates, and carry devastation along its course.

A deep crevice in a rock, when filled by a shower, is often the cause of the rock being torn asunder, and of part being precipitated.

Extensive walls or faces of masonry, intended to confine banks of sand or earth, if no openings were left for water to escape from behind them, would be burst after rain, unless they had the strength of flood-gates of the same size. Ignorance of this danger has led to some extraordinary catastrophes.

Other examples of the pressure in fluids being in all directions, and proportioned to the depth, are;—the swelling and bursting of leaden pipes when filled from a very elevated source:—the tearing up of the coverings of subterranean drains or water-courses, when during a flood any accident choaks them near their lower openings:—the violence with which water escapes by an opening near the bottom of any deep vessel, or enters by an opening or leak near the keel of a deep-floating ship:—the great strength required in the lower hoops and securities of those enormous vessels of



porter-brewers, called vats, some of which contain many thousand barrels of liquid.

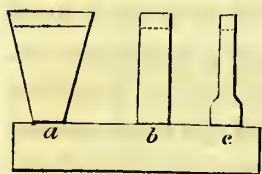
In speaking of the pressure of a fluid in all directions, some persons have difficulty in conceiving that there is an upward, as well as a downward and a lateral pressure. But, if in a fluid mass, the particles below had not a tendency upwards equal to the weight or downward pressure of the fluid over them, they could not support that fluid, which entirely rests upon them. Their tendency upwards is owing to the pressure around them from which they are trying to escape. Accordingly, if a long tube, open at both ends, and with a sliding plug or piston in it near one end, be partially plunged into water by the plugged end, the water is found to press the plug upwards with force proportioned to the depth to which it is carried, and exactly equal to the force with which water presses upon an equal extent of the bottom or side of any other vessel having in it the same depth ; or, with which, in the same vessel, it would press other plugs in other branches of the tube projecting in various directions. On removing such a plug altogether, the upward pressure is visibly proved and measured by the column of water pushed into the tube from below, and supported there to the level of the water around.

The pressure in a mass of fluid, is proportioned to the perpendicular depth, and is not at all influenced by the size, shape, or position of the containing vessel.

A body immersed in the water of a lake, one

foot under the surface, is just as much pressed upon, as if it were one foot under the surface of the sea, and no more than if it were one foot under the surface of a small cistern.

Suppose vessels differing from each other in form and capacity, as sketched here at *a*, *b*, and *c*, but all having flat bottoms, of exactly the same area; if fluid be poured into all to the same level or



perpendicular height, as represented here by the dotted lines, although the quantity be very different in each, the pressure on the bottom will be the same in all. This truth is easily proved experimentally, by having the bottoms moveable, and held to their places by weights or springs capable of measuring the pressure: or by letting the three vessels all communicate with the same vessel of water below them, and then observing that the water in all has still the same level.—These results are other exemplifications of the truths, “*pressure equal in all directions*,” “*pressure as depth*,” and “*pressure as the extent of surface*.” For as a column of the fluid, resting on the middle of each bottom, just presses with its whole weight, and therefore according to its altitude, this column could not remain at rest if there were any greater or less pressure than its own near it; then as the fluid really is at rest in all the cases, and in all a central column is of the same height, the pressure must be equal on all the bottoms. The case of the largest vessel *a* is in a degree illustrated by supposing the water in it to be suddenly converted

into smooth upright small columns or rods of ice or glass ; then evidently, only those pieces which rested on the bottom, could press on it, while the others would be supported by the oblique sides of the vessel, and by the lateral resistance of the pieces around them.

“ *Level surface of a fluid.*” (Read the Analysis.)

That the surface of a fluid must be level, follows from the facts of all the particles being equally attracted towards the centre of the earth, and being perfectly moveable among themselves. The particles forming the surface may be regarded as the tops of so many columns of particles, supported at any given level below, by a uniform resistance or pressure ;—for no particle of an inferior level can be at rest unless equally urged in all directions, and therefore all the particles at such a level, and which, by equally urging one-another, keep themselves at rest, must all be bearing the weight of equal columns : thus a higher column must sink and a lower one must rise, until just balanced by those around ; that is, until all become alike. Besides, just as a ball rolls down a slope or inclined plane, so do the particles of a fluid slide or move from any higher situation among themselves, to any lower unoccupied situation near them. The account now given explains why an accidental elevation or depression of a fluid surface, usually called a wave, continues to rise and fall, or to oscillate, for some time with gradually diminishing force ;—for when the mass is raised above the general level, it is not quite

supported, and therefore soon sinks, but in sinking, like a falling pendulum, it acquires momentum which carries it below the general level, until opposed and arrested by a resistance greater than its weight, it then rises again, but by acquiring new momentum in its rise, it has to fall again, again to rise, and this alternation continues, until the lateral sliding of the particles, and the friction among them, gradually destroy it.

A perfectly level surface on earth, really means one in which every particle is equi-distant from the centre of the earth, and it is therefore truly a spherical surface; but so large is the sphere, that if a slice of it of two miles in diameter were cut off, and laid on a perfect plane, the centre of the slice would only be four inches higher than the edges. Any small portion of it, therefore, for all common purposes, may be accounted a perfect plane.

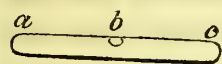
So truly smooth does a fluid surface become, that it forms a perfect mirror; that is, it reflects or throws back the rays of light which fall upon it so exactly in the order which they had on leaving the object, that an eye which receives them, may fancy the object to be placed in the direction of the mirror.—It was over the glassy surface of the fountain or the lake, that the shepherdesses of the young world bent themselves, to learn the charms which nature had betowed on them. And a child contemplates with wonder and delight, through the window of a still pool or gliding stream, another sky below the ground, with its clouds, and sun or stars; and another landscape, with inverted



woods and mountains, the supposed dwelling of fairy beings.

In the cutting of canals, the making of railways, and in many other operations of engineering, it is of essential importance to determine the level or horizontal direction at any place ; and this is usually done by a tube or glass *a c*, filled with

spirit except one bubble of air *b*, and called a spirit level. When this tube is horizontal, the bub-



ble has no tendency to move to either end ; but if the tube inclines ever so little, the bubble rises to the end which is highest ; or, to speak more correctly, the denser spirit falls down to the lower end, and forces the light bubble away from it. Such a tube properly fixed in a frame, with a telescope attached to it, or simply with sight-holes to look through, becomes the engineer's guide in many of his most important operations.

A hoop surrounding the earth would bend away from a perfectly straight line four inches in a mile. In cutting a level canal, therefore, which may be considered as part of a hoop, there must be everywhere a falling from the straight line, called by geometers a *tangent*, in the proportion now described. All rivers also have the curvature of hoops applied to the surface of the earth.

Canals leading from seaports to the interior of countries have generally to ascend ; but as water cannot become stagnant in any channel which is not level, the canal is divided, by gates or sluices, into portions at different levels, like steps of a stair, the rising at the joinings being generally from six



to twelve feet. The boats are raised or lowered from one level to another by the contrivance called a lock, which is merely a portion of the canal, of sufficient capacity for the boat to lie in, furnished with high walls, and with flood-gates at both ends ; so that when the gates below are shut, and water is gradually admitted from above, it becomes part of the high level, ready as such to deliver a boat, or receive one : and when the upper flood-gates are shut, and the water is gradually allowed to escape from the lock, it becomes a part of the low level, and a boat may enter it or leave it by its lower gates.

The cutting of canals is one of the great items in the mass of modern improvement, which both mark and hasten the progress of civilization. Adverting to the importance of easy intercourse, as explained in a former section, we need only say here, that a horse which can draw only one ton on our best roads, can draw thirty with the same speed in a canal-boat.

And what a glorious triumph to science and art it is, to be able to conduct vessels of all kinds, even those originally intended for the ocean surge alone, through the quiet valleys of an interior country ! In Scotland, now, along the Caledonian canal, a noble frigate may be seen, wandering as it were among the inland solitudes, and displaying her grace and majesty to the astonished gaze of the mountainshepherd ; and when she has traversed the kingdom, and visited the lonely lakes, whose waters until lately had borne only the skiff of the hunter, she descends again by the steps of her

liquid stair, and safely resumes her place among the waves.

It was lately in contemplation to lead a ship canal across the isthmus which joins North and South America. The elevation to which the canal must reach, to surmount the central ridge, is considerable, and will increase the difficulty ; but such important consequences would follow the accomplishment of the object, that, with the continuance of general peace, and the increase of political wisdom, it will probably be attained. If so, the loaded vessel, rising from the Atlantic, would soon be descried among the mountain heights, and, a few hours after, would be safely lodged in a port of the opposite sea ; having performed, by a near cut, a voyage which at present costs months of delay and hazard, in a tedious navigation round the whole southern continent.— And if the Red Sea and Mediterranean were joined in the same way, as has also been proposed, the operation would, in effect, bring India nearer to Europe, and would more and more strengthen the bonds of mutual utility and brotherhood among the nations of the earth. Then, indeed, might it be said with truth, that the world is a vast garden, given to man for his abode, of which every spot has its peculiar sweets and treasures ; but, because the cultivator of each may exchange a share of his produce for shares in return, the same general result follows as if every field or farm contained within itself the climates and soils and capabilities of the whole.

In a canal, the least deviation from the true

level would immediately cause any water admitted into it to flow towards the lower end. This flux to a lower situation is what is going on in the myriads of streams, which render the face of the earth a scene of such varied beauty and incessant change.

As in the animal body, from every the minutest point, a little vein, endowed with living power, takes the blood which has just brought life and nutriment to the part, and delivers it into a larger vein, whence it passes into a larger still, until at last, in the great reservoir of the heart, it meets the blood returned from every part of the body ; so in this terraqueous globe, where the magic moving power is simply fluid seeking its level, does the rain, which falls to sustain vegetable and animal life, and to renovate nature, glide from every point of the surface into a lower bed, and from thence into a lower still, until the countless streams, so formed, after every variety of course, combine to form the swelling rivers, which return the accumulated waters into the common reservoir of the ocean. In the living body, the arteries carry back the blood with renewed vitality to every point whence the veins had withdrawn it, and so, complete the circulation ; and in what may be called the living universe, the circulation is completed by the action of heat and of the atmosphere, which, from the extended face of the ocean, raise a constant exhalation of watery vapour of invisible purity, which the winds then carry away and deposit as rain or dew on every spot of the earth.

A very slight declivity suffices to give the run-

ning motion to water. Three inches per mile, in a smooth straight channel, gives a velocity of about three miles per hour. The Ganges, which gathers the waters of the Himalaya mountains, the loftiest in the world, is, at eighteen hundred miles from its mouth, only eight hundred feet above the level of the sea—that is, above twice the height of St. Paul's Church in London; and to fall these eight hundred feet, in its long course, the water takes nearly a month. The greater river Magdalena, in South America, whose channel, for a thousand miles, is between two ridges of the Andes, falls only five hundred feet in all that distance. Above the commencement of the thousand miles, it is seen descending in rapids and cataracts from the mountains. The gigantic Rio de la Plata has so gentle a descent to the ocean, that in Paraguay, fifteen hundred miles from its mouth, large ships arrive which have sailed against the current all the way, by the force of the wind alone: that is to say, which on the beautifully inclined plane of the stream, have been gradually lifted by the soft wind, and even against the current, to an elevation greater than that of our loftiest spires.

A small lake or extensive mill-pond, with uneven bottom, if suddenly emptied by a sluice or opening at its lowest part, would exhibit a number of pits or pools of various size and shape left among the inequalities. But supposing rain to fall, and frequently to recur, the water seeking its level would soon effect a very remarkable change. In consequence of each pool discharging over its lowest part, that is, sending out a streamlet either



into another lower pool, or into a channel leading directly to the sluice or opening, there would be a constant wearing down of the part or side of the pool over which the water were running, that is to say, a deepening of a breach or channel there, and the surface of water in the pool would be consequently becoming lower, while, at the same time, the bottom would be rising, owing to the deposit of sand or mud washed down by the rain from the elevations around; and these two operations continuing, the pool would at last altogether disappear. And by this change going on in every pool through the whole of the emptied mill-pond, the general bottom would at last exhibit only a varied or undulated surface of dry land, with a beautiful arrangement of ramifying water channels, all sloping with a precision unattainable by art, to the general mouth or estuary.—The reason that, in the supposed case, and in every other, a water-course soon becomes so singularly uniform, both as to dimension and descent, is, that any pits or hollows in it are filled up by the sand and mud carried along in the stream, and deposited where the current is slack; while any elevations are worn away by the action of the more rapid current which accompanies shallowness.

The above paragraph describes in miniature, what has been going on over the general face of our earth, ever since that convulsion of nature which produced its present form. In many places the phenomenon is already complete; in others it is only in progress. The whole of what is now dry land, has at some period been under water,



and much of it has evidently been a gradual deposition from water. By some extraordinary convulsion, therefore, our present continents and islands must have been thrown up from the bottom of an ocean, or an ocean must have subsided away from them ; and in either case the land must have emerged as chequered and unsightly, as the bottom of the emptied lake above supposed. And it is the gradual operation of *water seeking its level*, which has at last converted the earth into the paradise which we now behold.

The marks of the former state of the world, and of the progressive change, are every where most strikingly evident to the enlightened eye of philosophy. The present kingdom of Bohemia, for instance, is the bottom of one of the great lakes formerly existing over Europe. It is a basin or amphitheatre, formed by a wall of mountains; and the only gate or opening to it, is that remarkable one by which the water now escapes from it, and which evidently has been gradually cut or formed by the action of the running stream. As the bottom became uncovered owing to the sinking of the water, and the formation of a regular sloping channel from every part, the former lake was converted into a fine and fertile country, a fit habitation for man ; and the continued drain from it of the rains which fall over its surface, and either pass rapidly away, or sink into the earth and ooze again more gradually in the form of springs, is the beautiful river which we now call the Elbe.

In Switzerland, many of the vallies which were

formerly lakes, have the opening for the exit of water so narrow, that, as happened in one of them a few years ago, a mass of snow or ice falling into it, converts the valley once more into a lake. On the occasion alluded to, the accumulation of water within was very rapid; and although, from the danger foreseen to the country below, if the impediment should suddenly give way, every means was tried to remove the water gradually, the attempt had not succeeded when the frightful burst took place, and involved the inferior country in common ruin.

The magnificent Danube is the drain of a chain of basins or lakes, which must, at one time, have discharged or run over one into another; but owing to the continued stream cutting a passage at last low enough to empty them all, they are now regions of fertility, occupied by civilized man, instead of the fishes which held them formerly. This operation is still going on in all the lakes of the earth. The lake of Geneva, for instance, although confined by hard rock, is lowering its outlet, and the surface has consequently fallen within the period of accurate observation and records; and as, at the same time, the wearings of the neighbouring mountains, brought down by the winter torrents, are filling up its bed, if the town of Geneva last long enough, its inhabitants may have to speak of the river in the neighbouring valley, instead of the picturesque lake which now fills it. Already several towns and villages, which were close upon the lake a century ago, have fields and gardens spreading between them and the shore.

Illustrating this subject, it is very interesting to observe the contrast between the pure blue water of the Rhone issuing from the lake of Geneva, and the turbid streams which join its course a little farther down. The torrents which fall into the lake all around, are equally charged with the *debris* or wearings of the mountains; but, having deposited all their load in the still bosom of the lake, the pure water alone escapes to form the river. The streams, however, coming to the Rhone directly from the Alps, and bringing with them their charge of broken-down earth, even after they have joined it, are long distinguishable by their muddy waters. It is the mud deposited as here described, which is gradually filling up all lakes, and which has formed the vast regions of flat country seen about the mouths of great rivers. The greater part of Holland is deposition of this kind, the whole of lower Egypt, a great part of Bengal, &c. &c.

There are some lakes on the face of the earth which have no outlet towards the sea,—all the water which falls into them, being again carried off by evaporation alone—and such lakes are never of fresh water, because every substance, which, from the beginning of time, rain could dissolve in the regions around them, has necessarily been carried towards them by their feeding streams, and there has remained. The great majority of lakes, however, being basins with the water constantly running over at one part towards the sea, although all originally salt, have in the course of time become fresh, because their only supply, being directly

from the clouds, or from rivers and springs fed by the clouds, is fresh, while what runs away from them must always be carrying with it a proportion of any substance that remains dissolved in them. We thus see how the face of the earth has been gradually washed to a state of purity and freshness fitting it for the uses of man, and why the great ocean necessarily contains in solution all the substances which originally existed near the surface of the earth, soluble in water:—*viz.* all the saline substances. The city of Mexico stands in the centre of a vast and beautiful plain, 7,000 feet above the level of the sea, and surrounded by sublime ridges of mountains, many of them snow-capped. One side of the plain is a little lower than the other, and forms the bed of a lake, which is salt for the reasons stated above;—but the lake will not long be salt, for it now has an outlet. About 150 years ago, owing to unusual rains, an extraordinary increase of the water took place, and covered the pavements of the city. An artificial drain was then cut from the plain, at the distance of about sixty miles from the city, to the lower external country. This soon freed the city from the water, and since then, becoming every year deeper by the wearing effects of the uninterrupted stream, it is still lowering the surface of the lake, is daily rendering the water less salt, and is converting the vast salt marshes, which formerly surrounded the city, into fresh and fertile fields.

The vast continent of Australasia, or New Holland (as large as Europe), is supposed by some to have been formed at a different time from what is



called the old world, so different and peculiar are many of its animal and vegetable productions; and the idea of a later formation receives countenance from the existence of immense tracts of marshy or imperfectly drained land discovered in the interior, into which rivers flow, but seem not yet to have worn down a sufficient outlet or discharging channel towards the ocean.

Where the soil or bed of a country through which a water-track passes is not of a soft consistence, so as to allow readily the wearing down of higher parts, and the filling up of hollows by deposited sand, lakes, rapids, and great irregularities of current remain. We have, for instance, the line of lakes in North America, the rapids of the St. Lawrence, and the stupendous falls of Niagara, where at one leap the river gains a level lower by a hundred and sixty feet. A softer barrier than the rock over which the river pours, would soon be cut through, and the line of lakes would be emptied.

The contemplation of the fact, that water in seeking its level is constantly wearing where it rubs, and carrying the abraded portions down to lower levels, and ultimately to the bed of the ocean, brings irresistibly the awful idea, that this earthly abode of ours, owing to natural causes already in operation, can have but a limited existence in its present state. No shower falls that does not send portions of mountain and plain into the depths of the ocean, and thus cause a corresponding encroachment on the shores by the rising water; and with revolving ages, unless new con-

vulsions of nature disturb the progress, or art succeed, as in Holland and elsewhere, in shutting out the ocean from extensive low tracks by means of sea dykes or embankments, the dry land must at last disappear, and another gradual deluge embrace the globe.

There is, perhaps, nothing which illustrates in a more striking manner the exact resemblances among nature's phenomena, or their accordance with the few general expressions or laws which describe them all, than the perfect level of the ocean as a liquid surface. The sea never rises or falls in any place, even one inch, but in obedience to fixed laws, and therefore its changes may generally be foreseen and allowed for. For instance, the eastern trade-winds and other causes force the water of the Indian ocean towards the African coast, so as to keep the Red Sea about twenty feet above the general ocean level; and the Mediterranean is a little below that level, because the evaporation from it is greater than the supply of its rivers, causing it to receive an additional supply by the Strait of Gibraltar;—but in all such cases, the effect is as constant as the disturbing cause, and therefore can be calculated upon with confidence.

Were it not for this perfect exactness, in what a precarious state would the inhabitants exist on the sea-shores and on the banks of low rivers! Few of the inhabitants of London, perhaps, reflect, when standing by the side of their noble river, and gazing on the rapid flood-tide pouring inland through the bridges, that although sixty

miles from the sea, the water there is at the moment lower than the surface of the sea, which may at the time be heaving moreover in lofty waves, covered perhaps with wrecks and the drowning.

The horrible destruction that would follow any alteration in the level of the ocean, may be judged of by the effects of occasional floods, produced by rains and melting snow in the interior of countries, or by these combined with winds and high tides on the coasts. The flood at St. Petersburg, in 1825, was dreadful, in which strong westerly winds had retarded the flow of the Neva so much, that the water rose forty feet (the height of an ordinary house) above its usual mark, covered all the low parts of the town, and drowned thousands of the people.

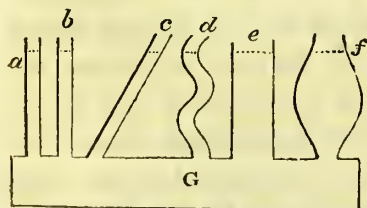
In Holland, which is a low flat, formed chiefly by the mud and sand brought down by the Rhine and neighbouring rivers, much of the country is really below the level of the common spring tides, and is only protected from daily inundations by artificial dykes or ramparts, made strong enough to resist the ocean. On one occasion the water broke into such an enclosure, and drowned more than sixty thousand people. What awful uncertainty then would hang over the existence of the Dutch, if the level of the sea were subject to change: for while we know that its waters, owing to the centrifugal force of the earth's rotation, are seventeen miles higher at the equator than at the poles, if the level, as now established, were from any cause to be suddenly changed but ten feet, millions of human beings would be the victims.

Where inundation is regularly periodical, as in the Nile and many other rivers, the hurtful effects can be guarded against, and the occurrence may even become useful, by fertilizing the soil.

Tracts of land in contact with rivers, of which land the surface lies between the levels of ebb and flood-tide, if surrounded with dykes, may be kept constantly covered with water, by opening the sluices only at high water; or may be kept constantly drained, by opening the sluices only at low water. A vast extent of rice fields, near the mouths of rivers in India and China, are managed in this way, the admission or exclusion of water being regulated by the age of the rice plant. A great part also of the rich sugar plantations of Demerara, Esequibo, &c., on the coast of South America, are in the same predicament; and another advantage which these have over the plantations on the West-India Islands, is the saving of the labour of transport effected by the canals which intersect all the fields.

*“If various tubes and vessels communicate with one-another, fluid admitted to them will rise to the same level in all.”* (Read the Analysis, p. 252.)

The following sketch may represent a variety of tubes and vessels, fixed upon and opening into the cistern or box G.



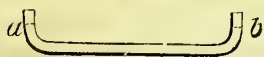
Water poured into any one would fill the box, and would then rise to the same level in all. The dotted lines



from *a* to *f*, may represent the surfaces of the fluid in the different vessels. In the figure at page 255, it was seen why, in all upright cylindrical vessels, as *a*, *b*, and *c*, the fluid rises to the same level; and the figure at p. 266, explained why shape of vessel cannot affect the level. Although in the oblique vessel *c*, represented here, there is more water than in *a*, still there is the same pressure at the bottom of both, because *c* supports part of the weight of its contained fluid on the principle of the inclined plane.

If a tube twenty miles long, and rising and descending among the inequalities of a country, were filled with water, and could have its ends brought together for comparison, it would exhibit two liquid surfaces having precisely the same level; and on either end being raised, the fluid would sink in it to overflow from the other.

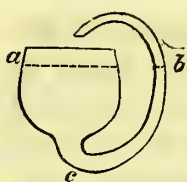
An easy mode of determining a level line at any spot is to have an open tube, bent up at its ends *a* and *b*, and nearly filled with liquid :



by then looking along the two liquid surfaces, or through floating *sights* resting on them, an observer looks in a line which is quite horizontal at the middle point between them.

If there were two lakes on adjoining hills of different heights, a pipe of communication descending across the valley and connecting them, would soon bring them to the same level; or if one were much higher than the other, would empty that one into the other

A projector thought that the vessel of his con-



trivance, represented here, was to solve the renowned problem of the perpetual motion. It was goblet-shaped, lessening gradually towards the bottom until it became a tube, turned upwards at *c*, and pointing with an open extremity into the goblet again. He reasoned thus: A pint of water in the goblet *a* must more than counterbalance an ounce which the tube *b* will contain, and must therefore be constantly pushing the ounce forward into the vessel again, and keeping up a stream or circulation, which will cease only when the water dries up. He was confounded when a trial shewed him the same level always in *a* and in *b*.

A glass tube inserted near the bottom of a cask or cistern of any sort, not air-tight above, which tube is then bent upwards, to appear on the outside like a barometer tube, shews by the elevation of fluid in it, the height of the greater mass of fluid within.

In like manner a tube brought from a river into a neighbouring cellar or pit, will indicate the height of the water in the river.

A knowledge of the truth, that water in pipes will always rise again to the height or level of its source, has enabled men in modern times to construct those admirable systems of iron pipes, which distribute water in great towns. The water being brought to any elevated site in or near the town, may be delivered from a reservoir there, by the effect of gravity alone, to every cistern which is under the level of the reservoir; the result not

being affected by the pipes having to rise over heights and to descend into valleys many times in their course.

On the hill north of London, on which Pentonville stands, there is such a reservoir to which water is brought from Hertfordshire, by a channel cut for the purpose upwards of thirty miles in length, and called the New River. Another reservoir has lately been constructed, by the West Middlesex Water Company, at Primrose Hill, higher than any house in town. It is filled by the operation of steam-engines at the Company's works near Hammersmith, five miles off. It will supply water to the summits of all the houses connected with it, and is exceedingly useful in cases of fire.

Many persons have believed that the ancients were ignorant of the law, that fluid in pipes rises to the level of its source, because in all the ruins of their aqueducts, the channel is a regular slope. Some of these aqueducts, as works of magnitude, are not inferior to the great wall of China, or the Egyptian Pyramids ; yet at the present day, a single pipe of cast-iron is made to answer the same purpose, and even more perfectly. It is now ascertained, however, that it was not ignorance of the principle, but want of fit material for making the pipes, which cost our forefathers such enormous labour.

The supply and distribution of water in a large city, particularly since the steam-engine has been added to the apparatus, approaches closely to the perfection of nature's own work in the circulation of blood through the animal body. From the

great pumps or a high reservoir, main pipes issue to the chief divisions of the town; these then send suitable branches to the streets, which branches again divide for the lanes and alleys; and at last subdivide until every house has its small leaden conduit carrying its precious freight, if required, even into the separate apartments, and yielding it any where to the turning of a cock. A corresponding arrangement of drains and sewers, most carefully constructed in obedience to the law of level, receives the water again when it has answered its purposes, and sends it to be purified in the great laboratory of the ocean. And so admirably complete and perfect is this counter-system of sloping channels, that a heavy shower may fall, and after washing and purifying every superficial spot of the city, and sweeping out all the subterranean passages, may within the space of an hour, form part of the river passing by. It is the recurrence of this almost miracle, of extensive, sudden, and perfect purification, which makes modern London the most healthy, while it is the largest city in the world.

English citizens have now become so habituated to the blessing of a supply of pure water, more than sufficient for all their purposes, that it no more surprises them than the regularly returning light of day or warmth of summer. But a retrospect into past times may still awaken them to a sense of their obligation to advancing art. How much of the anxiety and labour of men in former times had relation to the supply of this precious element! How often, formerly, has periodical



pestilence arisen from deficiency of water; and how often has fire devoured whole cities, which a timely supply of water might have saved! Kings have received almost divine honours for constructing aqueducts, to lead the pure streams from the mountains into the peopled towns. In the present day, it is he who has travelled on the sandy plains of Asia or Africa, where a well is more prized than mines of gold, or who has spent months on ship-board, where the fresh water is often doled out with more caution than the most precious product of the still, or who, in reading history, has vividly sympathized with the victims of siege or shipwreck, spreading out their garments to catch the rain from heaven, and then, with mad eagerness, sucking the delicious moisture—it is he who can appreciate fully the blessing of that abundant supply which most of us now so thoughtlessly enjoy. The author of this work will long remember the intense momentary regret with which, on once approaching a beautiful land after months spent at sea, he saw a stream of fresh water gliding over a rock into the salt waves—it appeared to him as if a most precious essence, by some accident, were pouring out to waste.

The subject of *fluid level* leads to the consideration of springs or wells, and of the operation of boring for water.

The water which falls from the clouds, and which must all ultimately return to the sea, may find its way to the rivers, either by running directly along the surface of soils which refuse it

admittance ; or by first sinking into porous earth, and again oozing out at lower situations in the form of springs. If a spring be as low as the bottom of the porous earth from which it issues, that is to say, as low as the surface of the impermeable clay or rock on which at some depth all such earth rests, it may drain the whole ; but if not, the water will stand at a certain level among the earth as it would among bullets in a water-tight vessel. If a hole or pit be then dug in such earth, reaching below the level of the water lying in it, the pit will soon be filled with water up to the level, and will be called a well. In many places this water-level is very far below the surface of the ground ; and in some places, by reason of the water having an easy drainage towards the sea, or of the superficial soil being altogether impermeable to it, there is none to be found within an accessible depth.

A remarkable illustration of this subject occurred a few years ago in Kent, on the occasion of cutting between Rochester and Gravesend the canal called the Thames and Medway Canal. This canal consists of but one cut or level, seven miles long, of which two are in a tunnel through the hill—which level is that of high water in the connected rivers ; the intention having been to let the canal be filled always from the rivers at high water :—but as the level of the subterranean water in the surrounding land, and therefore of all the inhabitant's wells there, is, as might be anticipated, half-way between the levels of high and low tides ; the salt water from the rivers was no sooner admitted to the

canal, than it spread into the land on either side, where the resisting internal water-level was lower, and destroyed all the wells. If the canal had been dug a few feet lower, the mischief would not have occurred, and the Company would have escaped paying the heavy damages, which rendered their undertaking a very ungainful speculation.

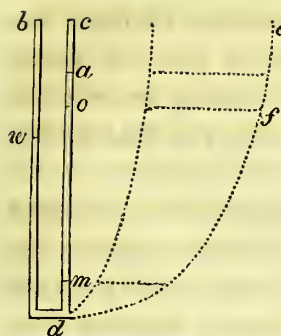
All the wells and springs in the world are merely the rain water which has sunk into the earth, appearing again, and gradually escaping at lower places: nature thus admirably making the bowels of the earth an ever-stored reservoir of the substance most indispensable to the comfort and existence of man, and of all living creatures. It is worthy of remark here, that high cultivation or agricultural improvement of a country has a great effect on the quantity of spring-water in it. While the face of a country is rough, the rain-water remains long among its inequalities, slowly sinking into the earth to feed the springs, or slowly running away from the surface as from bogs and marshes towards the rivers. The rivers hence have a comparatively uniform and regular supply, even when rain has not fallen for a long time:—but in a well-drained country, the rain, by a thousand prepared channels, finds its way to the brooks and rivers almost immediately, producing often dangerous floods or inundations of the neighbouring low grounds. A friend of the author had a water-fall and mill in Surrey, which he formerly let for a rent of £1,200 a year; but after agricultural improvements in the district from which the water came, the supply of water was generally either

superabundant or deficient, and the value of the mill was reduced to one-half.

The surface of our globe is formed of different strata or layers, as of clay, chalk, sand, gravel, &c. &c., which appear all to have been at former periods horizontal, formed under water, and to have been afterwards thrown up, by some convulsion or convulsions of nature, into every variety of position. In particular situations the upper surface is now concave or basin-shaped, the different strata or layers, when water-tight, being like cups or basins placed one within another; and as water poured in to fill the space between two basins so placed, would spring out to the height of its upper or level surface, through any hole made in the side of either, so on boring for water through an innermost or superior water-tight stratum or basin of earth, the water often springs out and rises far above the surface of the ground. London stands in a hollow of which the first-met layer is a basin of clay, placed over chalk, and on boring through the clay (sometimes of three hundred feet thickness), the water issues, and in many places will form a jet considerably above the surface of the ground; shewing that there is a higher source or level somewhere—as among the hills of Surrey, or those north of London.

When fluids of different kinds, and of different weights under the same bulk, are made to oppose, or to balance each other in communicating vessels—as water, for instance, in one leg of the bent tube *b d c*, and oil in the other—the surfaces will not all rest or settle at the same height or level,





but that of the lighter fluid will be just as much higher than that of the other as it is lighter. Thus a column of oil must be of a length as  $d o$ , to balance a column of water  $d w$ : and alcohol, because lighter than oil, to balance the same water, would

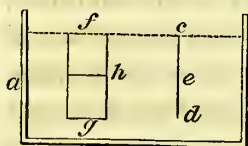
have to stand higher still, as at  $a$ ; while mercury, because thirteen times weightier than water, would stand only about  $m$ . The shape, size, or position of the vessels in which the opposing fluids might stand, would have no influence on the relative heights of the surfaces; for if we suppose a larger vessel, such as is represented here by the dotted lines between the letters  $e f m$ , to be substituted for the leg  $c d$  of the tube, the various fluids to balance the water in  $b d$ , would have to stand just as high in it, as in the smaller tube.

*“ A body immersed in a fluid, displaces exactly its own bulk of it, which quantity having been just supported by the fluid around, the body is held up with force exactly equal to the weight of the fluid displaced, and must sink or swim according as its own weight is greater or less than this.*

A bladder full of air, and maintaining the bulk of a pound of water, requires a force of one pound (except a few grains, the weight of the air) to plunge it under water. The same bulk of gold is held up in water with exactly the same force; so that, if previously balanced at the end of a weigh-

ing beam, it appears on immersion to have lost one pound of its weight. And a piece of wood, ivory, or any other substance, having exactly the same bulk, is opposed on entering the fluid by the same resistance.

The reason of this is obvious, for the immersed body takes the place of water which weighed one pound and yet was supported, and whose pressure was necessary for the equilibrium of the rest. In



a vessel of water represented here by the figure *a b*, let us attend to any portion of the water, a single column of particles for instance, represented

by the line *c d*: we know that each column is steadily supported in its place, because the particle of the liquid immediately under it is tending upwards to escape from the surrounding pressures, with force exactly equal to the weight of the column; and what is true of a column of single particles, is true of any other portion, such as the larger column represented by the figure *f h g*. If such portion weighed exactly a pound, the surface under it would be tending upwards with the force of a pound; and if the portion, without changing its bulk or form, were to become ice, it would still be exactly supported by the surface below pressing upwards with force of a pound; and further, if a similar column of wood, or stone, or metal, were there, the surrounding pressures would still be the same. Again, if we suppose only half the column to be solidified, the portion *h g* for instance, it would still be pressed upwards with a force of

one pound at  $g$ ; but its own weight of half a pound, and the weight of the half pound of water above it, would produce an exact balance and maintain rest.

It is very important to have clear notions on this subject; and as different minds apprehend such matters with different degrees of facility, and in different ways, we shall state the same general truth in other words.

Let us consider a mass of fluid as consisting of a vast number of extremely minute columns of single particles standing side by side, where every particle supports those above it by the tendency upwards which it acquires through the pressure of the fluid surrounding it. Now if we suppose the particles of a portion of the fluid mass, of any shape, to stick together, or to become ice without change of bulk or weight, that portion when solid would still be between the same forces as when fluid, and therefore would be equally supported, and would remain at rest. And if gold, or silver, or glass, or wood, having the same bulk, were substituted for the supposed ice, such new substance would still be sustained with the same force; so that a substance of exactly the same weight as the ice or water displaced, would have no tendency either to rise or to fall, more than the water itself had; but a substance heavier would sink, and one lighter would swim, and in either case with force exactly proportioned to the difference between its weight and that of an equal bulk of water.

Few persons, in now reading the statement of

this truth—in appearance so simple and obvious—would imagine that it had remained so long unknown, and that the discovery of it may be accounted one of the most important which human sagacity ever made,—but such is the case. We owe the discovery to one of the master-minds of antiquity—that of Archimedes. He caught the idea one day while his limbs were resting on the liquid support of a bath: and as his godlike intellect darted into futurity, and perceived many of the important uses to which the knowledge was applicable, he is said to have become so moved with admiration and delight, that he leapt from the water, and, unconscious of his nakedness, pursued his way homewards, calling out “*εὕρηκα, εὕρηκα*,” I have found it. He was thinking chiefly of the ready means, thus obtained, of ascertaining in all cases what has since been called the *specific gravity* of bodies, *viz.* the comparative weights of equal bulks of different substances; as of gold, or silver, or copper, or iron, compared with water; and in the case of mixtures, as of gold with silver for instance, of declaring at once the proportion present of each—important problems, which, until then, could not be correctly solved.

The hydrostatic law now explained, has since led to great advances in various arts. It may be regarded as a chief foundation of chemistry, for by it the chemist distinguishes one substance from another, distinguishes a pure from an impure substance, and discovers the nature of many mixtures or compounds. The merchant often judges by it of the worth of his merchandize. In any case it

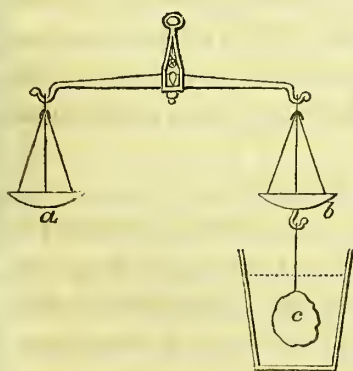


enables an inquirer to ascertain at once the exact size or solid bulk of a mass, however irregular—even of a bundle of twigs. It has become the cause of improvements in navigation, in marine architecture, and in many other arts.

We shall now discuss more particularly the subject of *comparative weights* or *specific gravities*.

“The force with which a body is held up in a fluid being the exact weight of its bulk of that fluid, by ascertaining this force and comparing it with the weight of the body itself, the comparative weights or SPECIFIC GRAVITIES are found.” (Read the Analysis, p. 252.)

If any body, *c*, a mass of gold for instance, be suspended by a thread or hair from the bottom of one scale *b* of a weighing-beam, and be balanced by weights put into the other scale *a*, and if a vessel of water be then lifted under it so that the



water shall surround it, the body is pushed up or supported by the water with force equal to the weight of the water which it displaces; the weights therefore, then required in the scale *b* to restore the balance, shew truly the exact weight

of the water displaced; or of water equal in bulk to the body; and the weights in the two opposite scales shew the comparative weights of the body

(1.)

U

and of its bulk of water. In the supposed case, whatever weight the gold had in the air, it would seem to lose, when the water surrounded it, about a nineteenth part of such weight ; that is, the water would support it with this force ; and gold would thus be proved to be about nineteen times as heavy as water.

In making a table of specific gravities, it was necessary to select a common standard with which all other substances should be compared, and this has been done in choosing water ; the reasons of preference being, that water can be so easily procured in a state of purity, and therefore of uniformity, in all situations. When we say, therefore, that gold is of the specific gravity 19, and copper 9, and cork  $\frac{1}{7}$ , we mean that these substances are just so much heavier or lighter than their bulk of pure water in its densest state, *viz.* at the temperature of 40 degrees of Fahrenheit's thermometer.

As the substances in nature differ as to form and other qualities, corresponding differences have to be made in the manner of ascertaining their specific gravities : the following cases are the most important.

*Solid bodies insoluble in water and heavier than it*,—as the metals, &c., are merely suspended by a thread or hair, having nearly the specific gravity of water, to one scale of the *hydrostatic balance* (simply a good weighing-beam with a water-vessel below one of the scales) ; and the body being first balanced or weighed in the air, and then in water, as already described, the weight and the loss, represented, if the operator chooses, by the weights

in the opposite scales, are the weights of equal bulks of the two substances ; and by finding, through the arithmetical operation of *division*, how often the weight of the water is contained in the weight of the solid, we find the specific gravity of the solid, or how much it is weightier than its bulk of water.

—It is almost superfluous to remark, that putting weights into the scale *b*, or taking them out of the scale *a*, are equivalent operations. We shall explain afterwards, that for very delicate purposes, bodies must be weighed first in a vacuum instead of in air, or a suitable allowance must be made ; for air itself supports a little any body immersed in it.

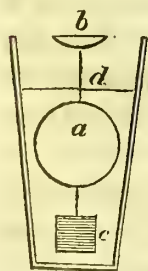
*Solids lighter than water*,—as cork, are weighed in it by attaching to them a mass of metal or glass heavy enough to sink them, and already balanced in water for the purpose ; or by making the line which connects them with the weighing-beam pass under a small pulley fixed at the bottom of the vessel, so that the rising of the end of the beam to which they are attached shall draw them down.

*A solid soluble in water*,—as a crystal of any salt, may be protected during the operation of weighing in water, by previously dipping it in melted wax, so as to leave a thin covering on it ; or it may be weighed in some liquid which does not dissolve it, allowance being afterwards made for the difference between the weight of such liquid and of water.

*Powders insoluble in water*,—such as gold-dust, are weighed in a glass cup, which has been previously balanced in water for the purpose.

*Powders soluble in water*—must be weighed in some other liquid. Mr. Leslie, the highly endowed professor of natural philosophy in the university of Edinburgh, has lately suggested a novel and ingenious mode of ascertaining the specific gravities of pulverized or porous bodies; but as it can be understood only by persons acquainted with the doctrines of *pneumatics*, the consideration of it must come under that head.

*Other liquids*—may be compared with water, in several ways. 1st. If a phial be made to hold exactly one thousand grains of distilled water, at the temperature of  $40^{\circ}$ , the weight of the same measure of any other liquid is found, by simply filling the phial, and weighing it. Of sulphuric acid, for instance, such a phial will contain nearly nineteen hundred grains, while of alcohol it will receive only about eight hundred. 2d. A bulb of glass, which loses one thousand grains when weighed in water (which thousand grains is therefore the weight of its bulk of water), may be weighed in other liquids, and the difference of loss marks the specific gravity, as in the last case. The bulb for this purpose may be of any size, but one which loses in water exactly one thousand grains, is pre-



ferable, from the simplicity thereby given to the calculations:—This remark applies also to the phial last mentioned. 3d. A contrivance which renders the beam and scales altogether unnecessary, is a hollow floating bulb of glass or metal *a*, with a slender stalk rising from it to support the little scale



or dish *b*, and with another stalk descending to carry the weight or weights at *c*, which serve as ballast to it. The whole is so adjusted that when displacing 1,000 grains, or other known quantity of pure water, it shall float with a certain mark upon the upper stalk just at the surface of the water. By then immersing it in other liquids, and finding how much weight must be added to or taken from it above or below to make it float in them at the same elevation, the comparative weights of these other liquids and of water are found:—or the difference of weight which makes it float at different elevations in water, having been previously ascertained, it will only be necessary, in any other case, to note exactly its elevation: an inch of the slender stalk may be equivalent to a difference of ten grains. This instrument is called an *hydrometer*. There are generally printed tables and directions accompanying all forms of it, telling the exact import of the several indications, and the allowances to be made for temperature, &c. It may be used for weighing solids as well as liquids, for if any mass be put into the saucer *b*, weights exactly equal to the mass must be taken out of the saucer *b*, or from below at *c*, to restore the equilibrium of the instrument. The mass may be afterwards placed at *c*, and weighed in water. 4th. The shortest mode of ascertaining the specific gravities of liquids is to have a set or series of small glass bubbles of different specific gravities, so that when they are thrown into any liquid, those heavier than it will sink, and those lighter will swim, while that one which marks its specific gravity will remain

merely suspended. The bubbles must of course be numbered, and the specific gravity of each be previously known.

A common use of hydrometers is to ascertain the quality of the distilled spirits brought to market, as of rum, brandy, gin, &c. All these consist of alcohol more or less diluted with water; and duty or tax is levied upon them in proportion to their strength, or the quantity of alcohol which they contain. A delicate hydrometer discovers this at once.

A shopkeeper in China sold to the purser of a ship, a quantity of distilled spirit according to a sample shewn; but, not standing in awe of conscience, he afterwards, in the privacy of his storehouse, added a certain quantity of water to each cask. The spirit having been delivered on board, and tried by the hydrometer, was discovered to be wanting in strength. When the vender was charged with the intended fraud, he at first denied it, for he knew of no human means which could have made the discovery; but on the exact quantity of water which had been mixed being specified, a superstitious dread seized him, and having confessed his roguery, he made ample amends. On the instrument of his detection being afterwards shewn to him, he offered any price for what he foresaw might be turned to great account in his trade.

The specific gravity of *aeriform substances* is ascertained by means of a glass flask of known size, furnished with a stop-cock. It is first weighed when emptied by the air-pump, and afterwards

when filled successively with water and with the different airs or gases. Comparison of the weights gives the specific gravities as already described.

The following table shews in round numbers the comparative weights or specific gravities of some common substances. Water is the standard kept in view, and any equal bulk of another substance is heavier or lighter than water, according to the numbers severally attached to them.

Platinum.....	22 $\frac{3}{4}$	Common Salt .....	2
Gold .....	19 $\frac{1}{3}$	Brick .....	2
Mercury.....	13 $\frac{1}{2}$	Alcohol .....	$\frac{8}{10}$
Copper .....	8 $\frac{3}{4}$	Æther .....	$\frac{3}{4}$
Steel and Iron .....	8	Cork.....	$\frac{1}{7}$
Diamond .....	3 $\frac{1}{2}$	Atmospheric Air.....	$\frac{1}{800}$
Glass .....	3	Hydrogen Gas.....	$\frac{1}{12000}$
Common Stones .....	2 $\frac{1}{2}$		

Complete tables are found in systems of Dictionaries of Chemistry.

A cubic foot of water happens to weigh very nearly one thousand ounces avoirdupois, or 62 $\frac{1}{2}$  pounds. Hence in the foregoing table, the figures denoting the specific gravities tell how many times a thousand ounces of the different substances a cubic foot contains. Of gold, for instance, a cubic foot contains more than nineteen thousand ounces, being worth in money about £63,000 sterling. A cubic foot of common air contains only a little more than one ounce; and of hydrogen gas, the lightest of ponderable things, a cubic foot contains less than a drachm.

The following facts also are illustrations of the truth, that a body immersed in a fluid is held up,

or has its entrance resisted, with force equal to the weight of the quantity of fluid which it displaces.

A stone which on land requires the strength of two men to lift it, may be lifted and carried in water by one man. There are cases, therefore, where the support of water thus rendered useful is equivalent to the assistance of an additional hand. A boy will often wonder why he can lift a certain stone to the surface of water, but no farther.

The invention of the diving-bell in modern times, having enabled men, in the building of piers, bridges, &c. to work under water almost as freely as above, many have experience of this influence of water: but workmen are generally surprised at first, to find that below, they can move much larger and heavier stones than they can in the air. Some had supposed the fact accounted for by saying that the denser air of the diving-bell when received into the lungs gave greater strength. In recovering property from a sunken ship by the diving-bell, every thing is found to be lighter in the proportion now stated.

This law explains also why stones, gravel, sand, and mud, are so easily moved by waves and currents. Many people expressed astonishment, in March 1825, to learn that at the Plymouth Breakwater, the storm had displaced blocks of stone, of many tons weight; but we now see that the moving water had only to overcome about half the weight of the stone.

When a person lies in a bath, the limbs are so nearly supported by the water as to require scarcely



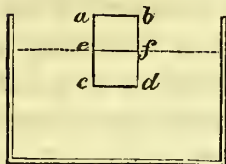
any exertion on the part of the individual. When this softest of all beds has been indulged in for half an hour or more, the person, on first lifting a limb out of the water, feels surprise at its great apparent weight. The workers about diving-bells always experience the sensation now spoken of, on returning to the air.

The bodies of most fishes are nearly of the specific gravity of water, and therefore, if lying in it without making exertion, they neither sink nor rise very quickly. When this subject was less understood, many persons believed that fishes had no weight in water; and it is related as a joke at the expense of philosophers, that a king having once proposed to his men of science, to explain this extraordinary fact, many profound disquisitions came forth, but not one of the competitors thought of trying what really was the fact. It was beneath the dignity of science in those days to make an experiment. At last a simple man balanced a vessel of water in scales, and on putting a fish into the water, shewed its scale preponderating just as much as if the fish had been weighed alone.

In the sense now explained, water is said to have no weight in water. The least force will raise a bucket of water from the bottom of a well to the surface; but if the bucket be lifted at all farther, its weight is felt, just in proportion to the part of it which is above the surface.

*“ A body lighter than its bulk of water will float, and with force proportioned to the difference.”*  
(Read the Analysis, p. 252.)

The reason of this is clear. If any body, the



cylinder  $a b c d$  for instance, be partially immersed in water, we know that the upward pressure of the water on the bottom  $c d$ , is exactly what served to sup-

port the water displaced by the body, *viz.* water of the bulk,  $e f c d$ . The body, therefore, that it may remain out as far as here represented, must have exactly the weight of the water which the immersed part of it displaces; and if it be lighter than this, it will rise further; if heavier, it will sink further, until the exact balance be produced.

Hence of any body which floats in water, a pound weight displaces just a pound of water, whether the body be very light in proportion to its bulk, as cork, or heavier, as a piece of dense wood. This is experimentally shewn by putting such bodies to float in a vessel originally full of water. The water displaced by each must run over the sides of the vessel, and may be caught and measured.

Hence a porcelain basin weighing four ounces will sink in water only as far as a similar wooden basin or bowl of the same weight; and the weight of either basin may be in the substance of which it is formed, or in any thing else put into it as a load.

Hence a boat made of iron floats just as high out of water as a boat of similar form and size made of wood, provided the iron be proportionately thinner than the wood, and therefore not heavier on the whole. An empty metallic pot or kettle is often seen floating with a great part of it above

the surface of the water.—Prejudice for a long time prevented iron boats from being used, although, for various purposes, they are superior to others; and there are still people who would fear to go on board of a ship built of the strong and singularly durable Indian teak, because it is heavier than water, and in the form of a log, therefore sinks in water. Many fine ships of the line, however, and East-Indiamen of fifteen hundred tons or more, are now built of teak.

Hence a ship carrying a thousand tons weight will just draw as much water, or float to the same depth, whether her cargo be of cotton or of lead:—and the exact weight of any ship and her cargo may be determined by finding how much water she displaces. In canal boats, which are generally of a simple form, this truth affords a ready rule for ascertaining the quantity of their load.

The human body, in an ordinary healthy state with the chest full of air, is lighter than water.

If this truth were generally and familiarly understood, it would lead to the saving of more lives, in cases of shipwreck and in other accidents, than all the mechanical life-preservers which man's ingenuity will ever contrive.

The human body with the chest full of air naturally floats with a bulk of about half the head above the water,—having then no more tendency to sink than a log of fir. That a person in water, therefore, may live and breathe, it is only necessary to keep the face uppermost. The reasons that in ordinary accidents so many people are

drowned who might easily be saved, are chiefly the following :—

1st. They believe that the body is heavier than water, and therefore that continued exertion is necessary to keep it from sinking ; and hence, instead of lying quietly on the back, with the face upwards, and with the face only out of the water, they generally assume the position of a swimmer, in which the face is downwards, and the whole head has to be kept out of the water to allow of breathing. Now, as a man cannot retain this position but by continued exertion, he is soon exhausted, even if a swimmer, and if he is not, the unskilful attempt will scarcely secure for him even a few respirations. The body raised for a moment by exertion above the natural level, sinks as far below it when the exertion ceases ; and the plunge, by appearing the commencement of a permanent sinking, terrifies the unpractised individual, and renders him an easier victim to his fate.—To convince a person learning to swim of the natural buoyancy of his body, it is a good plan to throw an egg into water about five feet deep, and then to desire him to bring it up again. He discovers that instead of his body with the chest full of air naturally sinking towards the egg, he has to *force* his way downwards, and is lifted again by the water as soon as he ceases his effort.

2d. They fear that water entering by the ears may drown, as if it entered by the nose or mouth, and they make a wasteful exertion of strength to prevent it ; the truth being, however, that it can only fill the outer ear, as far as the membrane of



the drum, where its presence is of no consequence. Every diver and swimmer has his ears thus filled with water, and cares not.

3d. Persons unaccustomed to the water, and in danger of being drowned, generally attempt in their struggle to keep their hands above the surface, from feeling as if their hands were imprisoned and useless while below ; but this act is most hurtful, because any part of the body held out of the water, in addition to the face which must be out, requires an effort to support it, which the individual is supposed at the time ill able to afford.

4th. They do not reflect, that when a log of wood or a human body is floating upright, with a small portion above the surface, in rough water, as at sea, every wave in passing must cover it completely for a little time, but will again leave its top projecting in the interval. The practised swimmer chooses this interval for breathing.

5th. They do not think of the importance of keeping the chest as full of air as possible ; the doing which has nearly the same effect as tying a bladder of air to the neck, and, without other effort, will cause nearly the whole head to remain above the water. If the chest be once emptied, while from the face being under water the person cannot inhale again, the body remains specifically heavier than water, and will sink.

When a man dives far, the pressure of deep water compresses, or diminishes the bulk of the air in his chest, so that without losing any of that air, he yet becomes really heavier than water, and would not again rise, but for the exertion of swim-

ming. The author of this work once saw a sailor (a fine-bodied West-India negro) fall into the calm sea from a yard-arm eighty feet high. The velocity on his reaching the water was so great, that he shot deep into it, and, of course, his chest was compressed as now explained: probably also the shock stunned him, for although he was an excellent swimmer, he only moved his arms feebly once or twice, and was then seen gradually sinking for a long time afterwards, until he appeared only as a black and distant speck, descending towards the unknown regions of the abyss.

Every person needs not learn to swim; but every one who makes voyages should have practised the easy lesson of resting in the water with the face out. The head, from the large quantity of bone in it, is a heavy part of the body, yet, owing to its proximity to the chest, which is comparatively light, a little action of adjustment with the hands easily keeps it uppermost; and there is an accompanying motion of the feet, called *treading the water*, not difficult to learn, which suffices to sustain the entire head above the surface. Many of the seventy passengers who were swallowed up on the sudden sinking of the Comet steam-boat near Greenock, in November 1825, might have been saved by the boats which so soon went to their assistance, had they known the truth which we are now explaining.

A man having to swim far, may occasionally rest on his back for a time, and resume his labour when he is somewhat refreshed.

So little is required to keep a swimmer's head

above water, that many individuals, altogether unacquainted with what regards swimming or floating, have been saved after shipwreck, by catching hold of a few floating chips or broken pieces of wood. An oar will suffice as a support to half a dozen people, provided no one of the number attempts by it to keep more than his head out of the water ; but often, in cases where it might be thus serviceable, from each person wishing to have as much of the security as possible, the number benefited is much less than it might be.

The most common contrivances, called *life-preservers*, for preventing drowning, are strings of corks put round the chest or neck, or air-tight bags applied round the upper part of the body, and filled when required by those who wear them blowing into them through valved pipes.

On the great rivers of China, where thousands of people find it more convenient to live in covered boats, than in houses upon the shore, the younger children have a hollow ball of some light material attached constantly to their necks, so that in their frequent falls overboard, they are not in danger.

Life-boats have a large quantity of cork mixed in their structure, or of air-tight vessels of thin copper or tin plate ; so that, even when the boats are filled with water, a considerable part still floats above the general surface.

Swimming is much easier to quadrupeds than to man, because the ordinary motion of their legs in walking and running is that which best supports them in swimming. Man is at first the most helpless of creatures in water. A horse while swim-

ming can carry his rider with half the body out of the water. Dogs commonly swim well on the first trial.—Swans, geese, and water-fowls in general, owing to the great thickness of feathers on the under part of their bodies, and the great volume of their lungs, and the hollowness of their bones, are so bulky and light, that they float upon the water like stately ships, moving themselves about by their webbed feet as oars. A water-fowl floating on plumage half as bulky as its naked body, has about half that body above the surface of the water; and similarly a man reclining on a floating mattress, as in the hydrostatic bed afterwards to be described, has nearly as much of his body above the level of the water-surface, as he forces of the mattress under it. His position therefore depends on the thickness of the mattress.

A man walking in deep water may tread upon sharp flints or broken glass with impunity, because his weight is nearly supported by the water.

But many men have been drowned in attempting to wade across the fords of rivers, from forgetting that the body is so supported by the water, and does not press on the bottom sufficiently to give a sure footing against a very trifling current. A man, therefore, carrying a weight on his head or in his hands held over his head, as a soldier bearing his arms and knapsack, may safely pass a river, where, without a load, he would be carried down the stream.

There is a mode practised in China of catching wild ducks, which requires that the catcher be well loaded or ballasted. Light grain being first strewed



upon the surface of the water to tempt them, a man hides himself in the midst of it, under what appears a gourd or basket drifting with the stream, and when the flock approaches and surrounds him, he quickly obtains a rich booty by snatching the creatures down one by one—adroitly making them disappear as if they were diving, and then securing them below. Each bird becomes as a piece of cork attached to his body.

Fishes can change their specific gravity, by diminishing or increasing the size of a little air-bag contained in their body. It is because this bag is situated towards the under side of the body, that a dead fish floats with the belly uppermost.

Animal substances, in undergoing the process of putrefaction, give out much aeriform matter. Hence the bodies of persons drowned and remaining in the water, generally swell after a time, and rise to the surface, again to sink when the still increasing quantity of air shall burst the containing parts.

A floating body sinks to the same depth whether the mass of fluid supporting it be great or small :—as is seen when a porcelain basin is placed first in a pond, and then in a second basin only so much larger than itself that a spoonful or two of water suffices to fill up the interval between them. One ounce of water in the latter way may float a thing weighing a pound or more, exhibiting another instance of the *hydrostatic paradox* :—And if the largest ship of war were received into a dock, or case, so exactly fitting it that there were only half an inch of interval between it and the wall or side

of the containing space, it would float as completely, when the few hogsheads of water required to fill this little interval up to its usual water-mark were poured in, as if it were on the high sea. In some canal locks, the boats just fit the space in which they have to rise and fall, and thus the expense of water at the lock is diminished.

The preceding examples of floating are all illustrations also of the truth that the pressure of a fluid on any immersed body is exactly proportioned to the depth and extent of the surface pressed upon. The lateral pressures just balance one-another, and the upward pressure has to be balanced by the weight of the body.

Similar reasoning to that which proves that the whole weight of a body acts as if lodged in the point called its centre of gravity, proves that the whole buoyancy of a body, or the upward push of the fluid in which a body is immersed, acts as if lodged in the point which was the centre of gravity of the fluid displaced. This point consequently is called the "centre of buoyancy."

A floating body, to be stable in its position, either must have its *centre of gravity* below the *centre of buoyancy*—in which case it resembles a pendulum; or it must have a very broad bearing on the water, so that any inclination may cause the centre of gravity to ascend,—in which case it resembles a cradle or rocking-horse.

Hence arises, in the stowing of a ship's cargo, the necessity of putting the heavy merchandize underneath, and generally of putting iron ballast

under all the merchandize. Hence, also, the danger of having a cargo or ballast which is liable to shift its place. A ship loaded entirely with stones, is sometimes lost by a wave making her incline for a moment so much that the load shifts to one side, which is then kept down. For a similar reason, a cargo of salt or sugar has a peculiar danger attached to it, for if the ship leak, the cargo may be dissolved, and then pumped out with the bilge water, leaving her with altered trim. In a fleet coming home from India in 1809, four fine ships disappeared during a hurricane off the Isle of France, and from what happened to the other ships that were saved, the cause of the destruction was supposed to be, that the saltpetre of the cargoes had been dissolved and pumped out, and that the ships in consequence became unmanageable.

Bladders used by beginners in swimming are dangerous, unless secured so as not to shift towards the lower part of the body.

A great inventor (in his own estimation) published to the world, that he had solved the important problem of walking safely upon the water; and he invited a crowd to witness his first essay. He stepped boldly upon the wave, equipped in bulky cork boots, which he had previously tried in a butt of water at home; but it soon appeared that he had not pondered sufficiently on the centres of gravity and of flotation, for in the next instant all that was to be seen of him was a pair of legs sticking out of the water, the movements of which shewed that he was by no means at his ease. He

was picked up by help at hand, and, with his genius cooled and schooled by the event, was conducted home.—Some soldiers once finding a few cork *jackets* among old military stores, determined to try them ; but mistaking the shoulder straps for lower fastenings, they put them on as *drawers*, and on then plunging in, with the hope of being able to sit pleasantly on the water, their heavy heads went down, and they were nearly drowned.

When, on the return of summer, the ice breaks up in the polar regions, immense islands of it are set afloat, rising high into the air and sinking deep into the sea. The melting process, in most cases, does not go on equally in the water and in the air, and from the mass consequently changing form, its stability is often lost, and one of the grandest phenomena in nature follows—the overturning of a mountain—the sudden subversion of an island—producing a tumult in the ocean around, felt often at the distance of many leagues.

The phenomena of pressure, floating, &c. in fluids, vary in proportion to the weight or specific gravity of the fluid.

A ship draws less water, or swims lighter, by one thirty-fifth, in the heavy salt water of the sea than in the fresh water of a river : and for the same reason a man swimming supports himself more easily in the sea than in a river.

Many kinds of wood that float in water will sink in oil.

A man floats on mercury as the lightest cork floats on water, and with practice he might be able to walk upon mercury.



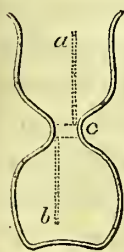
Had the water of our ocean been but a little heavier than it is, men after shipwreck might have died of famine and cold, but would not have been drowned.

Oil floats on water, but sinks in alcohol or ether. The term *proof spirit* means spirit light enough for oil to sink in it. The strength of spirit is proportioned to its lightness.

Cream rises in milk, and forms a covering to it.

Blood, allowed to rest after flowing from the living body, separates into parts or layers, which arrange themselves according to their specific gravities. The buffy coat of inflammation (where this exists) is uppermost, forming the surface of the general coagulum: towards the lower part of the coagulum there is an accumulation of red globules; and the whole of the solid part floats in the serum, which is therefore lowest of all. When the red globules escape from the coagulum they fall to the bottom even of the serum.

Wine, if slowly and carefully poured on water, will float upon it. In a vessel shaped like a common sand-glass, only with a larger opening between the chambers at *c*, if wine be put into the under chamber, and water into the upper, the two liquids will gradually change places: and if the lower half of the glass be covered, so as to leave the upper half with the appearance of a simple goblet, the water will seem to have been changed into wine. The liquids are less mixed, and change places sooner, when there is a tube *b* to carry the water down to the bottom



without touching the wine, and a tube *a* to carry the wine directly to the top.

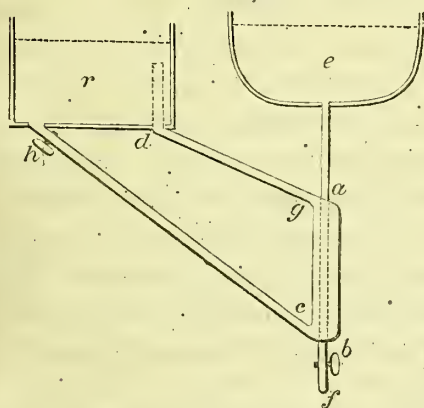
Mercury, water, oil, air, and some other fluids may all be shaken together in the same vessel, and on standing will separate again and arrange themselves in the order of their specific gravities.

When, in a mass of water, part of it is heated more than the rest, that part, by its expansion, becomes specifically lighter than the rest, and rises to the surface. Hence, when heat is applied to the bottom of a vessel containing water, a circulation is established, which goes on from the first moment until the operation of heating finishes:—water is always rising from the hotter parts of the vessel, and descending over the colder parts.

In like manner, when a tall glass containing hot water is dipped into cold water, a downward current takes place within the glass near the sides all round, and there is an upward current in the middle. This motion may be rendered very obvious by small portions of amber thrown into the water, for these being nearly of the specific gravity of water, rise and descend with it. On account of the current established in such cases, heat applied to the bottom of a vessel of liquid is soon equally diffused over it; but heat applied at the top is there confined, because the heated and lighter fluid does not descend. Water may be made to boil at its surface, while a piece of ice lies at the bottom. The converse is impossible.

The current in a fluid, produced by local change of temperature, is an important part of the following process, which the author deems applicable to

various useful purposes.—Heat may be transferred from one liquid to another, without mixing them, by making the hot liquid descend in a very thin metallic tube, through the cold liquid rising around it in a larger tube. Boiling water from the vessel *e*, for instance, may descend slowly by the small tube *e a b f*, which is surrounded from *a* to *b* by cold



water ascending through the tube *c g*. Then, as the temperature of two liquids, brought so nearly into contact with each other, will not, after a very short time, differ in any one place

more than a few degrees, it follows that the water lately cold, will, on leaving the part of the tube *g*, which is in contact with the boiling water descending directly from *e*, be nearly boiling, while the water lately hot will, on leaving the tube at *b*, which is in contact with cold water just arrived from *h*, be itself nearly cold: and thus equal quantities of hot and cold water will have exchanged temperatures. The flux of the hot water is to be regulated by a cock *b*, and that of the cold water by a cock *h*. The water in the part of the tube *c g d* rises, because it is hotter and therefore specifically lighter than that in the part *h c*.—The author believes that an apparatus made on this principle, with an arrangement of many thin flat

tubes instead of a single large tube, for the descending fluid, and a spacious box *c g* to contain these and the rising fluid, would be an excellent refrigerator in a distilling apparatus; and for cooling the wort of brewers; or would serve as a means of diminishing the expense of warm-baths, by transferring the heat from the water lately used to pure water. In distilling, the *wash* or *low wines* about to enter the still, might be used as the cold condensing fluid to surround the worm or vapour tubes, and thus, without expense, would be heated in its progress to the still. Half the original expense of a great porter brewery is in the construction of the numerous water-tight floors on which the hot wort is thinly spread to cool. The practice of warm bathing, so conducive to health, is less common in this country, because the present expense is so great.

It is a general truth in nature, that substances contract in size as they cool. There is, however, in water, a curious exception to this rule, which, operating through the principle of specific gravities, effects most important purposes in the economy of nature. Water contracts only down to the temperature of  $40^{\circ}$ ; below which, towards  $32^{\circ}$ , or the freezing point, it goes on dilating again, and as ice is much lighter than as a fluid. Ice therefore floats on the surface of water, and being a very slow conductor of heat, defends the water underneath from the cold air, and preserves it liquid, and a fit dwelling for the finny tribe, until the return of the mild season. And not only is the extreme of cold below thus prevented, but because very cold



water remains floating on the surface of a wintry lake, as cream floats on milk, it preserves underneath that warmth which is agreeable to the fishes, just as very hot water in summer remains uppermost, preserving underneath an agreeable coolness. By the dilatation of very cold water, then, and the formation of ice, nature has prepared a winter garb for the inhabited lakes and rivers, as complete and effectual as for terrestrial animals, by the periodical thickening of their wool or fur. Had ice become heavier than water, so that it must have fallen to the bottom, and have left the surface without protection, a deep lake, in European winters, would have been frozen into a solid lifeless mass, which summer suns would no more have melted than they now do the glaciers of Switzerland. But for this important exception, therefore, to a general law of nature, many of the now most fertile and lovely portions of the earth's surface would have remained for ever barren and uninhabited wastes.

## PART III.

## THE PHENOMENA OF FLUIDS.

## SECTION II.—PNEUMATICS.

## ANALYSIS OF THE SECTION.

*In aeriform fluids, that is, in such as have their particles held far apart by a mutual repulsion, which yields, however, to any force applied, so that the mass suffers great change of volume under different degrees of compression,—the phenomena are modified by the GREAT LIGHTNESS and ELASTICITY of the fluids, but are still in strict accordance with the general properties of fluids already explained, viz. PRESSURE EQUAL IN ALL DIRECTIONS—PRESSURE AS THE DEPTH—LEVEL SURFACE, and FLUID SUPPORT. The pressure of air, in all directions, and as the depth, may be studied in the effects of our atmosphere—on solids—on liquids :—or when it concurs with heat, in producing the phenomena of boiling, evaporation, clouds, rain, dew, &c. ; or when, by varying in degree, it allows certain substances to exist sometimes in the liquid and sometimes in the aeriform states. The fluid support in air is exemplified by balloons, the ascent of flame and smoke, winds, &c.*

WHAT a change has taken place in the degree of man's knowledge of nature, since philosophers thought that air was one of four primary elements, viz. *air, fire, water, and earth*, of which all things were composed, and each of which was for ever distinct from the others. We now know that air or gas is merely an accidental state, in which any body may exist, according to the quantity of heat pervading it: the body being solid when the ab-

sence of heat allows its atoms to obey freely their mutual attraction, and to cohere—as in ice, for instance ; being liquid, when so much heat is present as nearly to balance the attraction, and to let them slide freely among each other—as they do in water ; and being aeriform when still more heat is added, causing the atoms mutually to repel and dart asunder to a great distance—as they do in steam. Put in any one of these three states, the various substances are as much themselves as in the others, and at the command of the chemist will assume any of the forms which he desires. As most substances in nature have a different relation to heat, there are some which, at the medium temperature of our earth are solid, some which are liquid, and some aeriform. The solids, in general, are the heaviest under a given volume, and therefore sink down and form the great mass or centre of the earth ; the liquids follow next in order, and float upon this solid centre, filling up its inequalities with a level surface, so as to constitute the ocean ; while the airs are the lightest of all, and as a second ocean, rest above the sea and above the highest mountains, to an elevation of about fifty miles. Among the substances whose relation to heat causes them, when not restrained in certain combinations, to assume the form of air at very low temperatures, there are two in particular, viz. *oxygen* and *nitrogen*, which are very abundant in nature in such uncombined state, and of these, therefore, the atmosphere chiefly consists ; but smaller portions of almost every other substance are found in it. Water, among the supplementary matters, is much more

abundant than any of the others, and in its various states of cloud, mist, rain, dew, and snow, it answers a thousand useful purposes, and serves beautifully to vary the scenes of nature. The atmosphere is about fifty miles high or deep, and therefore, in relation to the bulk of the earth, is as a covering of one-tenth of an inch in thickness to a common library globe of a foot in diameter.

The atmospheric ocean is the great laboratory in which most of the actions of life go on, and on the composition of which they depend. A human being requires for breathing a gallon of fresh air every minute, dying equally if deprived of air, or if confined to the same. All other animals also require fresh air, but in various proportions. And in the vegetable creation, the beautiful green leaf and delicate flower are merely broad and tender expansions of surface for the contact of the vivifying air. Animals give out to the atmosphere a substance which vegetables absorb, and vegetables, by the absorption, fit the air again for the use of animals; so that, upon the whole, in the various changes of nature, there is a perfect balancing of actions, which preserves the atmospheric mass in a uniform state, constantly fit for its admirable purposes.

While the ancients had that notion of air, which made them apply to it vaguely, and almost indifferently, the names of *air*, *ether*, *spirit*, *breath*, *life*, &c., they never dreamt of making experiments upon it, with a view to prove its relation to common matter:—and one of the most beautiful portions of the modern history of man's progress



in knowledge, is that which exhibits the light gradually breaking in upon this most interesting subject. Galileo was led to conclude that air made a definite pressure upon things at the surface of the earth; Torricelli and Pascal proved that this was occasioned by its weight, and hence moreover they deduced the height of the aerial ocean; Priestly, Black, Lavoisier, and others, discovered that air might be united with a metal, so as to increase its weight, and to produce a compound of totally new qualities, for they shewed that many of the ores of our mines are merely metals concealed, by being thus united with a substance, which when set free ascends as one of the ingredients of the atmosphere. They at last analyzed the atmosphere itself, and exhibited its two great ingredients as distinct substances. And within a few years the nature of air or gas has been so thoroughly investigated, that we can now take a little of many a light, invisible, impalpable fluid such as we breathe, and squeezing the heat out of it by strong pressure, can make its particles collapse from their aeriform distances to assume the state of a tranquil fluid; which may then be retained as such for ever, or may be decomposed and made solid in combination with other bodies, or may be again set at liberty.

The suspicion once excited, that air was as much a material fluid as water, only much less dense, by reason of a greater separation and repulsion of the particles, it was easy to follow out the parallel, and to confirm the supposition by reference to the commonest facts. Thus, a leathern sack or pouch,

opened and dipped into water so as to become full, if its mouth be then carefully closed, retains the water, and its sides cannot afterwards be pressed together : a similar sack or bladder, opened out, and then closed in air, is found to remain, in a corresponding way, bulky and resisting, and forms what is called an air-pillow. The motion of a flat board is resisted in water : the motion of a fan is resisted in the air. Masses of wood, sand, and pebbles, are rolled along or floated by currents of water : chaff, feathers, and even rooted trees, are swept away by currents of air. There are mills driven by water ; and there are mills driven by the wind. Oil set free under the surface of water, or placed there in a bladder, rises to the surface : hot air or hydrogen gas placed in a balloon, rises in the air. A fish moves itself by its fins in water : a bird moves itself by its wings in the air ; and as on taking the water from a vessel in which a fish swims, the creature falls to the bottom, gasps a few moments, and dies ; so, on exhausting the air from a vessel in which birds or butterflies are enclosed, their useless wings may flap ; but they sink to the bottom, and if the cruel experiment be continued, they soon become motionless and for ever.

We proceed now to prove that air or gas, as a fluid, differs from the other fluids which we call liquids, only in the two circumstances of great lightness or rarity, and of being very extensively elastic, that is to say, the particles being so related, that pressure brings them much more nearly into contact, and on ceasing, allows them to regain their former distance.

*Lightness of Air.*

The lightness or rarity of atmospheric air, as it is found on the general surface of the earth, is such, that if, by the action of a pump, a bag of it holding a cubic foot be emptied into the copper ball of an air-gun, the ball weighs about an ounce and a quarter more than before. The same volume of water weighs nearly a thousand ounces; so that common air is about eight hundred times lighter than water. Other gases, or substances in the aeriform state, have their various specific gravities, just as the same substances have when liquid or solid. Thus water in the form of air, that is to say, when existing as steam, and of the common density, is little more than half as heavy as the same bulk of common air: hydrogen is only one-fourteenth part as heavy: and carbonic acid gas, which is the air that rises out of soda-water, brisk ale, champagne wine, &c., is so much heavier, that even in the atmosphere, it may be poured out of one open vessel into another, as a liquid might, or, more exactly, as water might be poured out under oil.

*Elasticity of Air.*

A small bladder full of air may be pressed or squeezed between the hands so as to be much reduced in size, but on being relieved from the pressure it will immediately resume its former bulk.

If a metallic tube or barrel of perfectly uniform bore *a*, *b*, be fitted with a moveable plug or piston



c, which is covered with leather and oiled, so as to slide up and down without allowing the air to pass by its sides, the air between the piston and the close bottom *b* may be compressed to a hundredth or less of its usual bulk ; but when allowed, will push the piston back again with the same force as it opposed to the condensation, and will recover the volume which it had before the experiment.

Again, if the plug at the commencement of the experiment were only an inch from the bottom, inclosing air of the usual density, on drawing it up to the top, the inch of air beneath it would expand so as to occupy the whole tube, having become, of course, proportionally less dense.

To the question why the air, which admits of such various density, is found to have that certain degree of it met with at the surface of the earth, we answer, that as the water, in any place near the bottom of the ocean, is pressed with force exactly proportioned to the quantity of water above it, so the air at the surface of the earth bears the pressure of the superincumbent mass of air, and, on account of its extensive elasticity, suffers, like the lowermost bags of cotton or wool in a great heap, that degree of compression which the superincumbent mass is calculated to produce. We shall see below, that the density of the air near the earth is changing with every circumstance which affects the weight of the atmosphere above, as winds, clouds, rain, &c., and that it



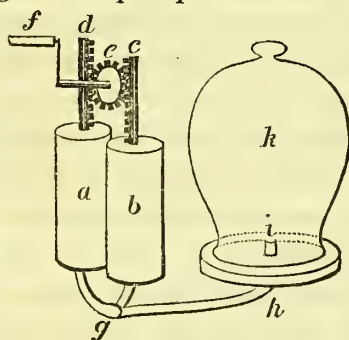
bears relation to the altitude of the place of observation above the level of the sea.

The tube with its piston, described in the last page, becomes, according to the position of its valves, either a syringe for injecting and condensing air, or a pump for exhausting or removing it from any vessel; both operations depending on the elasticity of air.

A barrel and piston is a *condensing syringe*, when, in a passage of communication between the bottom of the syringe and a receiving vessel, there is a flap or *valve* allowing air to pass towards the receiver but not to return. The piston, therefore, at each stroke forces what the barrel contains of air into the receiver. When the piston is lifted again after the stroke, air re-enters the barrel from the atmosphere, either through a valve in the piston, or through a small hole near the top of the barrel.—That useful contrivance, a *valve*, for whatever purpose used, and in whatever way formed, is in principle merely a moveable flap, placed on an opening, against which it is held by its weight, or by some other gentle and yielding force. Such a flap, it is evident, will allow fluid to pass only in one direction, *viz.* outwards from the opening, for any fluid tending inwards must shut the flap, and press it the closer, the greater the tendency.

To convert a forcing syringe or pump into an exhausting syringe or pump, commonly called an *air-pump*, it is only necessary to reverse the position of the valves; then, on the descent of the

piston, all the air between it and the bottom, instead of entering the vessel or receiver, as in the last case, escapes by a valve in the piston itself towards the atmosphere, and, on the rising of the piston, a perfect vacuum would be left under it, but that the valve below, then opened by the elasticity of the air in the receiver, allows a part of that air to follow it. Thus, at each stroke, a quantity of the air, proportioned to the size of the pump, is removed from the receiver. In a good air-pump there are two similar pumping barrels, as *a* and *b*, to



quicken the operation of exhausting; and both are worked at the same time by the reciprocating winch or handle *f*, with its pinion *e*, acting on the teeth of the piston rods *d* and *c*.

This double construction has the farther advantage, that the atmospheric pressure, if fifteen pounds per square inch on the upper surface of either piston, and which for a single piston would have to be overcome by the worker in lifting it, is here balanced always by the corresponding pressure on the other piston. Both pumps communicate with a tube *g h*, which at *h* rises tightly through the round plate of the machine to *i*. This flat plate is so smooth, that a glass bell or *receiver k*, with a smooth ground lip, when placed upon it, forms an air-tight joining. On working the pump, such a bell is exhausted of its air, and fitted for showing

the many interesting phenomena which the air-pump can display,—and which will pass under review as we proceed. The supporting framework of the pump is not shewn here.

The law of the elasticity of air is, that its spring, or resistance to compression, increases exactly with its density, or the quantity of it collected in a given space. Hence, by finding in any case either the density of the air, or the spring, or the compressing force, we know all the three.

It has been ascertained by experiments described a few pages further on, that in the atmospheric ocean surrounding the earth, there are nearly fifteen pounds of air above every square inch of the surface of the earth; and that the air nearest the earth, and bearing this superincumbent weight or pressure, has the density of an ounce and a-quarter of weight to a cubic foot of volume. We further find that such air is reduced to half its bulk, or becomes of what is called double atmospheric density, by an additional pressure of fifteen pounds on the inch, and of triple density by triple pressure, and so forth; and on the other hand, that it dilates to double bulk if the pressure be diminished to half, and to any greater bulk, even beyond a thousand-fold, if the pressure be diminished in a corresponding degree; and any air bearing a given force or pressure, is always acting as a spring of that force on whatever it touches.

It is very important to be familiar with this truth or law, for it holds very nearly with respect to all

aeriform fluids as well as common air, and throws light, therefore, on the action of steam-engines, air-guns, and pneumatic machines generally. It also explains the condition of our atmosphere as to density at various elevations; telling us, for instance, that when a balloon has risen through half of the atmospherical mass, the air around it will be of only half the density which exists at the surface of the earth.

We know not exactly to what extent the rarefaction of air may go on the removal of pressure; in other words, at what distance the gravity of the particles becomes just a balance to their mutual repulsion; and therefore we know not exactly what the degree of rarity is at the top of our atmosphere; but we know that it must be exceedingly great, from the fact that the air left in the receiver of an air-pump has still spring or elasticity enough to lift the valve of the pump, when less remains than the thousandth part of the original quantity. In the most perfect air-pumps, that the exhaustion may be as complete as possible, the machine itself is made to raise the valve.

The expansion of air is well illustrated by a bladder, having a very little air in it, placed under the receiver of an air-pump. On exhausting the receiver, the bladder gradually swells, with force sufficient to lift a moderate weight laid upon it, and at last appears quite full, and may even be burst. A shrivelled apple treated in the same way becomes plump. The explanation of such phenomena is, that at first the air in the bladder or apple is in a state of condensation, like all air at



the surface of the earth under the pressure of the superincumbent atmosphere ; but that its volume increases as that pressure is diminished by the air-pump :—it is rarefied in the same proportion as the air which remains in the receiver surrounding it.

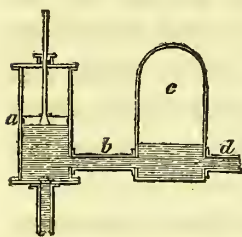
The curious instrument called the air-gun has a strong globular vessel of copper attached under the lock, into which air is usually forced to be thirty or forty times as dense as the air in the atmosphere around ; hence the pressure or elasticity tending outwards is thirty or forty times fifteen pounds on the inch, and when the valve is opened for an instant by the action of the lock, a portion of the air issues and propels the charge with this force. The effect of air thus condensed nearly equals that of gunpowder, and one charge of the ball suffices for many shots, the force however becoming less for every successive discharge.

If a bottle or vessel *a b*, partly filled with water, have a tube *c d* passed tightly through its cork to near the bottom of the water ; and if more air be then forced through this tube in any way, so as to accumulate in the upper part of the vessel above the water surface *a b* ; on turning the cock *c*, which opens the tube, the elasticity of the condensed air will press the water out as a beautiful jet, to a height proportioned to the condensation, and gradually diminishing as the condensation diminishes. Or if such a vessel, with air of common density, be placed under a tall air-pump receiver,



on working the pump so as to diminish the density of the air in the receiver, the jet of water will equally arise.—A table-lamp, by the force of condensed air, may be supplied with oil from a reservoir far below the wick: and lately an enema-syringe and a shower-bath have been constructed on the same principle.

The elasticity of air is rendered very serviceable in connexion with great water-pumps, such as those used for the supply of cities. A pump throws its water by a distinct gush at each stroke, while the current through the pipe towards the city



should be uniform. Now uniformity is attained by causing the gushes from the pump *a* to enter by the passage *b* at one side of a large vessel *c*, of which the upper part is full of condensed air, and from the other

side of which, at *d*, the water issues on its way. The air in this vessel (called the *air-vessel*) is condensed, as a spring, by the entering water, and its resisting elasticity, both immediately, and afterwards during the interval of the strokes, forces the water along the pipe *d*. Each entering gush has only the effect of compressing the air a little more for the time, while the flow in the great pipe continues nearly uniform. The pump itself is made to take in a little air at each stroke, so that not only is the vessel always supplied, but some air is constantly passing on with the water, and effecting the highly useful purpose of giving an elasticity to the whole contents of the pipe and its ramifications.

The same object is attained by the same means in the fire-engine used to check conflagration. In it there are generally several water-pumps working together, which throw their interrupted supply into an air-vessel, from whence it passes in a nearly uniform jet to the point desired.

The compressibility and corresponding spring of air are remarkably exhibited in that singular contrivance of modern times, the *diving-bell*, in which men now descend with safety to considerable depths in the ocean, there to reside and labour, attaining many objects of high importance to them:—they recover sunken treasures,—they are enabled to pursue works of submarine architecture, as in constructing light-houses and noble harbours, where formerly no foundations could have been laid, &c. The diving-bell, in point of utility, has proved a remarkable contrast to its sister invention, the balloon, which, although so wondrously bearing man aloft to the regions of the clouds, has brought him as yet little advantage to compensate for the many fatal accidents which its use has occasioned.

The diving-bell is a large heavy open-mouthed vessel, with accommodation in it for one or more persons. It is let down into the water with its mouth undermost, from a crane to which it is suspended, and which rests on a suitable carriage either on the shore or on the deck of a ship or barge fitted for its service. On first entering the water it appears full of air; but air being compressible according to the law now explained, and the pressure of the water around the descending

bell increasing with the depth, the volume of the air gradually diminishes, and at thirty-four feet is reduced to half. The bell then, unless more air be supplied, will of course be half full of water, and a person breathing in it, at each inspiration will receive twice as much air into the lungs as when breathing at the surface. A constant supply of fresh air is sent down to the bell by a forcing-pump above; and the heated and contaminated air, which has served for respiration, and which rises to the top of the bell, is allowed to escape by a cock placed there for the purpose. The men who work at a distance from the bell have tubes of communication with it, by which they inhale the air required; and they allow the used air to rise through the water above them. A man cannot breathe comfortably by such a tube if he be either much above or much below the level of the water in the bell: for if above, the air in the bell is more compressed than his chest, and is forced towards him so as to require an effort to control its admission; and if below, his chest is bearing greater pressure than the air in the bell, and he must therefore act strongly with the muscles of the ribs to draw the air down to him. A phenomenon similar to this takes place when two bladders of air are connected by a long tube, and immersed in water to unequal depths, the air being always strongly forced from the lower into the upper one, because the lower one is more pressed. The difficulty of pumping air down to the diving-bell increases, of course, with the depth to which it has descended: for if the bell be so low that the water

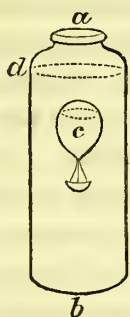


is pressing on the air in it with a force of fifteen pounds per inch (which would happen at thirty-four feet), it is evident that a syringe or pump cannot inject more air unless it act with a force greater than this. Divers might often, if not always, more conveniently receive their supply of air through tubes from an air-vessel kept charged to the necessary density in a boat over them, or on the shore, than from a bell below. If they would, moreover, dress in India-rubber cloth, and use a hood of metal with windows for the head, they might work under water without wetting any part but their hands.

It is remarkable, when the use of the diving-bell has become so familiar, that a kindred and still more simple contrivance of the same class has not been introduced for certain purposes, particularly of sudden emergency, such as to aid in the recovery of the bodies of drowning persons. A ten-gallon cask, or vessel of any kind, filled with air, and made heavy enough just to sink in water, with a breathing tube from it like that of a diving-bell, would be a provision of air for a man below water for ten minutes; and a man with it under his arm, might instantly descend from a boat, or walk from the shore, into water of any depth, to recover the body of a fellow-creature lately sunk, and in time probably to save the life, which a few minutes wasted in waiting or in unsuccessful dragging would suffer to be lost. The author would propose this as an addition to the apparatus of the Humane Society for the recovery of persons apparently drowned.—It shews the remoteness from common trains of thinking of the truths

connected with the constitution of our atmosphere and sea, when a means so simple and easily procured should never have been thought of or tried in any way by pearl-fishers, or by persons who gain their bread by diving to recover things dropped overboard in harbours or anchoring stations ; all of whom have hitherto been limited to the single gulp of air taken on descending. In the case of a man working under water, cask after cask of air might be sent down, to enable him to remain as long as necessary.

There is an exceedingly beautiful philosophical toy, of which the action depends chiefly on the elasticity of air ; and as it moreover



illustrates most of the laws of fluidity, it is deemed worthy of description here. It is a small balloon or thin globe of glass *c*, having an opening at the bottom, and its little car or basket hanging to it. If put to float in water while the globe contains air only, it is so light that half the globe remains above the surface ; but water may be introduced to adjust the specific gravity of the whole, until it become only a little less than that of water. If the balloon be then placed in a tall jar of water *a* *b*, the mouth of which is closely covered by bladder-skin or India-rubber tied upon it, on pressing such covering with the hand, the balloon will immediately descend in the water, to rise again when the pressure ceases, and will float about, rising, or falling, or standing still, according to the pressure made. The reason of this is, that pressure

on the top of the jar first condenses the air between the cover and the water surface ; this condensation then presses upon the water below, and by influencing it through its whole extent, compresses also the air in the balloon-globe, forcing as much more water into this as to render the balloon heavier than water, and therefore heavy enough to sink. As soon as the pressure ceases, the elasticity of the air in the balloon repels the lately entered water, and the machine, becoming as before, lighter than water, ascends to the top. If the balloon be adjusted to have a specific gravity too nearly that of water, it will not rise of itself after once reaching the bottom, because the pressure of the water then above it will perpetuate the condensation of the air which caused it to descend. It may even then, however, be made to rise again by inclining the water-jar to one side, so that the perpendicular height of water over it shall be diminished.

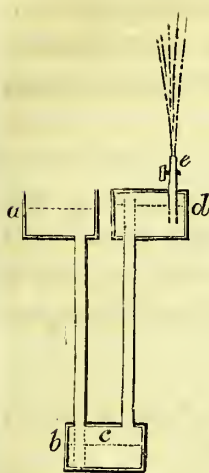
This toy proves many things—the *materiality* of air, by the pressure of the hand on the top being communicated to the water below through the air in the upper part of the jar—the *compressibility* of air, by what happens in the globe just before it descends—the *elastic force* of air shewn in expansion, when, on the pressure ceasing, the water is again expelled from the globe—the *lightness* of air, in the buoyancy of the globe:—it shews also that in a fluid *the pressure is in all directions*, because the effects happen in whatever position the jar be held—it shews that *pressure is as the depth*, because less pressure of the hand is required the farther

that the globe has descended in the water—and it exemplifies many circumstances of *fluid support*. A young person, therefore, familiar with this toy, has learned the leading truths of hydrostatics and pneumatics, and has had much amusement as well as instruction.

On the same principle as the balloon now described, three or four little figures of men may be formed of glass, hollow within, and having each a minute opening at the heel, by which water may pass in or out. If these be placed in a jar as the balloon was, and be adjusted by the quantity of water admitted into them, so that, in specific gravity, they shall differ a little from each other, and if then, a gradually increased pressure be made on the cover of the jar, the heaviest figure will descend first, and the others will follow in succession; and they will stop or return to the surface in reverse order when the pressure ceases. A person while exhibiting these figures to spectators who do not understand them, may appear only carelessly to rest his hand on the cover of the jar while he is making the required pressure, and he will seem to have the power of ordering their movements by his will. If the jar containing the figures be inverted, and the cover be placed over a hole in the table, through which, unobserved, the exhibitor can act by a rod rising through the hole and obeying his foot, he may produce the most amusing and surprising evolutions among the little men, in perfect obedience to his word of command.

The beautiful fountain, called the fountain of Hiero, by which water is made to spout far above





its source, depends for its action upon the resisting elasticity of compressed air. The vessel *d* is first filled with water, while *b* and *a* contain air only. On then pouring water into *a*, the water of *d* darts upwards through the jet-pipe *e*, to an elevation nearly equal to the length of the tube from *a* to *b*. The reason is, that the water from *a* descends by the tube to *b*, and compresses the air at *c*; which compression conveyed along the other tube from *c* to *d*, acts on the water in the vessel *d*, and causes it to jet. As the pressure is produced by the column of water *a b*, the jet is proportioned to the length of that column.—This kind of fountain may have its parts concealed under a variety of forms, as here exemplified, and may thus become a beautiful ornament among flowers in a summer drawing-room. It may be made of size to play for an hour or more, and it will always recommence on the water being shifted from the low to the high reservoir.—The useful table-lamp, consisting of a simple column or

pillar with the oil rising to the flame from far below, is a Hiero's fountain, only the oil, instead of being allowed to jet out, rises in a tube to the

flame. The contrivance for maintaining the two columns always of the same length, notwithstanding the expenditure of oil, has to be explained some pages hence.

Having now explained the two peculiarities which distinguish aeriform from other fluids, *viz.* their *lightness* and extensive *elasticity*, we proceed to shew that they have the four other properties already described under hydrostatics, as belonging to fluids generally : and first,

“ *Pressure in all directions.*” (Read the Analyses at pages 252 and 320.)

A quantity of air or gas shut up in any vessel and compressed, is equally affected throughout, and its tendency to escape from the pressure is equal in all directions, as is proved by the force necessary to keep similar valves close wherever placed. Hence the hydrostatic press and hydrostatic bellows described in last section, which depend for their action on this law, may be worked by air or gas as by a liquid.

Owing to this law, air, when allowed, will always rush from where there is more pressure to where there is less. The actions of the common fire-bellows, and of the animal chest in breathing, blowing, sucking, &c. are so many instances.

The suddenness with which any compression made on part of a confined aeriform fluid is communicated through the whole, is strikingly seen in the simultaneous increase or burst of all the gas-lights over an extensive building, or even in a long street, at any instant when the force supplying the gas is augmented.

Many very interesting illustrations of the fluid pressure of air being in all directions will occur under the next head, joined with proofs of the atmospheric pressure being as the depth.

*“ Pressure as the depth.”*

On first approaching this subject, a person is naturally surprised to hear the depth or height of the atmosphere spoken of as something perfectly ascertained, although nobody can ever have approached the surface to measure it; but science often furnishes means of reaching precise truth, in cases where ignorance would not even dream of the possibility of making an approximation. It may facilitate the apprehension of this point as regards air, to describe first, some parallel cases in which water is concerned.

The bottom of a lake evidently supports all the water in the lake, and each portion bears just the weight of the water directly over it: a means then of ascertaining the weight or pressure of water on any portion of the bottom, would tell how much water stood over that portion, and by the known relation of the weight and bulk of water, would tell also the depth at that part. In like manner, the ocean of air which surrounds the globe rests with its whole weight upon the surface of the globe, and each portion of the surface bears its share: if we ascertain then the pressure of the atmosphere on a given extent of surface, we find how much air is standing directly over it; in other words, the weight of a column of air resting on such surface as its base, and reaching to the top

of the atmosphere. Having then the weight of the whole column, and finding the weight of a given bulk of it at the bottom (ascertained as described at page 325), and knowing the law of aerial elasticity (explained at page 329), we determine the depth or height of the column by a simple calculation. Now, accurate experiments shew that there are nearly fifteen pounds of air over every square inch of the earth's surface ; producing the same pressure as would be made by a depth of water of thirty-four feet, or by a depth of quicksilver of thirty inches ; and from this fact, and the ascertained lightness and elasticity of air, we know that its depth on earth must be nearly fifty miles, which, as already stated, is about as much in relation to the size of the earth as a tenth of an inch is to a globe of one foot diameter. The remaining part of this section has chiefly to trace the effects of this mass of matter resting upon the earth's surface, and as a fluid embracing and compressing every object placed there.

Water is a substance much more obvious to the human senses than air, and which is constantly under observation ; yet many of its most important agencies escape the notice of common observers. Few persons, for instance, of themselves discover the law explained in the last section, of the pressure in water being proportioned to the depth : but when made to observe that a piece of cork plunged deep into it is compressed to much smaller bulk, and that strong empty vessels of glass, or even of metal, under the same circumstances, are crushed or broken inwards, and that pieces of



sunken wood are at great depths filled with water through all their pores, so as to become nearly as heavy as stone, &c., their minds are roused to a sense of the important fact, that a fluid presses, and in proportion to its depth. If the truths of hydrostatics thus escape notice, we need not wonder that those of pneumatics escape still longer.

If a piece of bladder-skin or a pane of glass be laid at the bottom of a vessel holding water, the bladder or glass exhibits no sign of being pressed upon, although it bears on its upper side the whole weight of the water directly above it; the reason being that water beneath the bladder resists just as strongly as the water above presses, in the same way that one stone in a pillar resists those above it: but if the bladder be tied closely over the mouth of a common drinking-glass or tumbler filled with water, and placed at the bottom of the vessel, and if then, by means of a syringe or pump, the water be extracted from within the glass, the bladder itself has to bear the whole pressure of the water above it (independently of a pressure of air to be explained afterwards), and will probably be torn or burst. The degree of pressure, and consequently the depth of the water, in such a case, might be ascertained by placing some support, of which the action could be measured, under the bladder to sustain it after the removal of the interior water.—Now this case may be closely copied in our atmosphere or sea of air. A glass held in the hand is immersed in the fluid air, and is full of it, as the other glass was supposed full of water: its mouth may be covered

over with bladder, and no external pressure will be apparent, because there is a resistance of the air within, just equal to the pressure of the air on the outside :—but if the air be extracted from under the covering, by means of an air-pump, the bladder is first seen sinking down and becoming hollow from the weight of the air over it, and at last bursting inwards with a great noise or crack. By placing a circular piece of wood under the bladder-skin, for it to rest on, and a spring of known force to support the wood, we may ascertain very nearly the weight and pressure of the air over it. This mode, however, of ascertaining the weight of the atmosphere, is not that commonly used, but is described here as a good illustration of the present subject ; the problem being solved much more elegantly and accurately by means of the barometer described further on. The phenomenon of atmospheric pressure is often exhibited by placing the hand on the mouth of a glass so as to cover it closely, and then extracting the air from underneath the hand : the weight of the atmosphere holds the hand down upon the mouth of the glass with a force of fifteen pounds to the inch.

As should follow, from the pressure of fifteen pounds per inch thus detected at the surface of the earth being the weight of our superincumbent atmosphere, we find that exactly as we rise from the earth, and leave part of the atmosphere beneath us, the pressure diminishes. This fact now furnishes the readiest means of ascertaining the height of mountains and of balloon ascents, as will be explained in considering the barometer.

After the many explanations here given of fluid pressure being equal in all directions, it is almost superfluous to remark, that the downward weight of the atmosphere becomes a pressure in all directions. This is seen in the fact of the bladder described above, being as readily burst if turned sideways as if turned directly upwards. Every body or substance, therefore, on the surface of the earth, dead or living, solid or fluid, is compressed with this force. In general the pressure on one side of a body is just balanced by the equal pressure on the other, so that no sensible effect follows; and it is on this account that philosophers were so long in discovering it at all, and that half-informed persons are still disposed to doubt its existence; but the proofs offered on all sides to the now awakened attention are irresistible. We shall first speak of

*“ Atmospheric pressure on solids.”*

The atmosphere, then, presses on the two sides of a plate of glass or metal, with force of fifteen pounds on the inch. Under ordinary circumstances no sensible effect follows, because the opposite pressures counterbalance; but if two plates of smooth glass or metal be laid against each other, and the air be prevented from entering between them, they cannot be separated by less force than fifteen pounds per inch of their surface.

In like manner, to draw down the piston of a syringe from the bottom of its barrel, while no air is allowed to enter between them, requires force of

fifteen pounds to the square inch of surface of the piston. But if the experiment be made in the exhausted receiver of an air-pump, the piston falls by its own weight. It is pushed back immediately on re-admitting the air. Wherever a vacuum is produced at the surface of the earth, there is an external pressure, of the force stated, seeking admittance all round.

An air-pump receiver of five inches diameter has nearly twenty square inches of surface in its upper part or roof, and bears a weight or pressure of atmosphere, of twenty times fifteen, or three hundred pounds. While it has air within it, this pressure is exactly balanced, and is not sensible; but when exhausted on the plate of the air-pump, it is pressed against the plate with this force. As the atmospheric pressure is in all directions, the pump-plate of course is equally pressed upwards against the receiver, and the sides of the receiver are pressed towards each other. This explains why air-pump receivers must be made arched or of dome-shape to withstand the great pressure. A flat piece of glass of great thickness, laid upon the upper mouth of a receiver, so as to form an air-tight cover to it, is broken instantly by exhausting the air beneath; and a bottle or receiver with flat sides, when exhausted, suffers in the same manner.

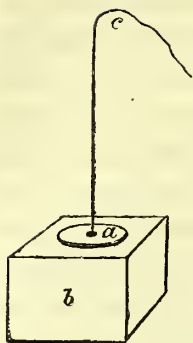
Illustrative of this pressure on solids there is the experiment of the Magdeburgh hemispheres, as it is called. Two hollow half globes of metal *a* and *b*, are fitted to each other, so that their lips when touching may be air-tight. While there is





air between them or within, resisting the pressure of the outward air, they can be separated from each other without difficulty; but when the air is exhausted from within by the air-pump, a force is required to separate them of as many times fifteen pounds as there are square inches in the area of the mouth. The air is extracted by unscrewing one of the handles at *b*, and then connecting the remaining stalk (which is hollow, and has a stop-cock) with the air-pump.—This experiment merits recollection, because it was one of the first which drew attention to the material nature and properties of the air; and it astonished the world. Otto Guericke, Burgomaster of Magdeburgh, the inventor, had hemispheres made of three feet in diameter, and once when he exhausted them, on the occasion of a public exhibition, twenty coach-horses of the Emperor were unable to pull them asunder. There being no air-pump when Guericke began his experiments, although he himself invented it afterwards, he originally emptied the balls of their air by first filling them with water, and then extracting the water by a common pump or syringe applied at the bottom.

It is a phenomenon of the same kind as the last described, when a boy with his foot presses a circular piece of wet leather as *a*, against a flat-faced stone as *b*, and then lifts the stone by pulling at a cord *c*, rising from the centre of the leather. If the leather be so close in its texture that air cannot pass through it, and stiff enough not to be



puckered or drawn together, he must exert a force before detaching it, of as many times fifteen pounds as there are square inches of surface covered by it, for such is the weight or pressure of the air over it, while there is no counterbalancing pressure underneath nearer than on the other side of the stone. The weight of the stone that may be lifted is thus determined by the size of the leather. The contrivance has been called a *sucker*, or *pneumatic tractor*. A very large *sucker* applied upon a rock or wall, would resist the pull of horses like the Magdeburgh hemispheres.

This contrivance seems suited to some purposes of surgery. It might assist, for instance, in raising depressed portions of a fractured skull, and might thus sometimes save the operation of trepanning :—for such a purpose it would be preferable to the small cupping-glass sometimes used, from its being perfectly inactive, except during the instants when pulled at ; whereas the cupping-glass, by keeping up a continued flow of blood to the part, might do injury. There is another surgical application spoken of in the last *section* of the present *part*, which the professional reader may consult immediately.

It is from having feet that act on the principle of the tractor, that the common fly and other insects can move along ceilings, and even polished surfaces of glass or metal, with their bodies hang-

ing downwards ; and there are many marine animals which attach themselves to rocks, or other objects, by a similar action.

If two pneumatic tractors be applied to each other, men pulling opposite ways, to separate them, must act with a force of fifteen pounds to the square inch of the surface of contact, as if they were separating the Magdeburgh hemispheres.

The case of the pneumatic tractor may be well illustrated by an experiment made in a vessel containing a liquid. If a body with a flat surface be applied to the bottom of the vessel so as perfectly to exclude the liquid, the body bears the whole weight of liquid directly over it, and cannot be detached without force equal to this. The case is striking when a flat piece of cork is pushed against the smooth bottom or side of a vessel containing mercury, and is found not to rise again when the hand is withdrawn from it, but to be firmly held down by the weight of the mercury. We have to remark that in such experiments made in vessels open to the air, the weight of the atmosphere on the liquid adds a pressure of fifteen pounds on every inch of the surface of a body immersed in it.

“ *Atmospheric pressure on liquids.*”

The pressure of the atmosphere on liquids produces many important effects, and now that we comprehend them, we wonder that they should have been so long misunderstood. We have familiar examples of it in the working of pumps and syphons. All such phenomena, in former times,

were referred to what was called *nature's horror of a vacuum*, or to an obscurely imagined *principle of suction*. It was not until the time of Galileo that their true nature began to be detected. The discovery has led to many very important results in the arts.

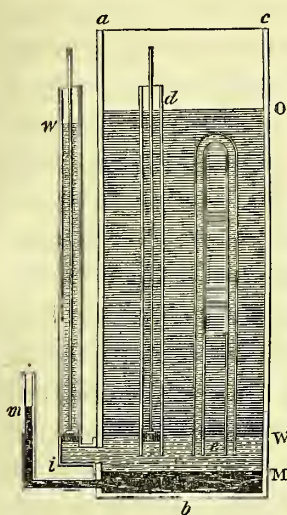
Persons may at first have a difficulty in conceiving that a fluid so rare and subtile as air should affect or resist a dense liquid like water: but the action or resistance of air in contact with water is familiarly shewn in the facts, that a glass does not become full of water when plunged, with its open mouth downwards, from the air into water; and that when a tube open at both ends has been partially immersed in water, and therefore partially filled, the water can be forced out of it by blowing air in at the upper end, to return only when the blowing ceases. Then, it may be recollected that a hundred pounds of feathers are as great a load as a hundred pounds of lead.

That there are fifteen pounds of air above every square inch of the earth's surface, is confirmed by the effects above described of the atmospheric pressure on solids; and we now proceed to shew that many of the phenomena among liquids, which long appeared so mysterious, are merely the necessary consequences of the same pressure upon them. It will facilitate the comprehension of these effects, if we first view them as they may be produced by more visible agents, *viz.* by one liquid pressing upon another; and for this purpose the author has contrived the apparatus represented below, in which a layer of oil rests



upon a layer of water, or upon a layer of mercury.

It has already been shewn, that an ocean of oil spread over the earth, to have the same weight as our atmosphere, would require to be about thirty-seven feet deep. A vessel, then, *a b c*, with water in it up to the level *W*, and with thirty-seven feet of oil above this, up to the level *O*, is fitted to illustrate many of the phenomena of atmospheric pressure on liquids. The following are the seven principal cases.



1st. The weight of the oil pressing with a force of 15lbs. per inch on the water at *W*, would not at all disturb the level surface of the water.—Neither does the weight of the atmosphere of 15lbs. per inch disturb any liquid surface.

2d. If the oil were gradually poured into the vessel *a b c*, over the water, the water would rise in the tube *i w*, as already explained by the figure at page 291; so that when there were thirty-seven feet in height, or fifteen pounds in weight of oil on the inch, the water in *i w* would stand thirty-four feet above its level in the large vessel. If these thirty-four feet of water were then lifted out of the tube by a plug or piston drawn up from the bottom of it at *i*, a second equal quantity would be pressed up by the oil, to be removed, if de-

sired, in the same way as the first, and the tube and piston would constitute a pump.—Now when the atmosphere instead of the oil is allowed to press upon the water-surface in such a vessel, but is excluded from the tube, the water rises in the tube thirty-four feet, as in the last case ; and if this quantity be lifted out of the tube by a piston, a second equal quantity is pressed up, and the tube and piston become a complete example of the common *lifting or sucking-pump*. We have to describe it more particularly hereafter.

3d. If there were a quantity of mercury or of quicksilver at the bottom of the vessel *abc*, filling it up to the level *M*, and if a tube *im* issued from under this level, the mercury pressed upon by thirty-seven feet of oil, would rise in this short tube as the water did in the larger ; but by reason of its greater specific gravity it would only reach a height of thirty inches above its level, the water, having stood at thirty-four feet.—Now thirty inches of mercury is the height of column which the atmospheric pressure acting in the same way really produces, as is seen in a similar apparatus made expressly for measuring that pressure, and called a *barometer*, or *measure of weight*.

4th. If a tube *d*, of an inch square, and open at both ends, were plunged into the oil, it would of course always be full up to the level of the oil on the outside of it ; and if it were pushed low enough to touch the water at *W*, it would just contain fifteen pounds of oil resting on an inch square of the water-surface at its mouth ; which surface would therefore be bearing a weight of fifteen pounds

like every inch of the surface around, but would not yield, owing to the force with which it tended upwards to escape from the pressure corresponding to its depth in the oil. Then if the tube were pushed a little farther down, and if, by a piston or plug in it, the fifteen pounds of oil were lifted out of it, water would rise into it until enough had entered to reproduce the pressure of fifteen pounds on the surface below as before; that is to say, the water would rise thirty-four feet, as in the external tube *wi*. This internal tube and piston again would form a *pump*.—In like manner, when a tube open at both ends is plunged from the air into water, the air presses on the surface of the water within the tube, as on the surface around it, with a force of fifteen pounds to the inch, and the two surfaces are not affected by the equal pressures; but if, by a piston, we lift the air out of the tube, as we suppose the oil lifted in the last experiment, the water will then rise, following the piston, to the altitude of thirty-four feet. This arrangement of parts is the most usual for the *lifting* or *household pump*.

5th. If a common bottle or vessel of any other shape, as the bent tube *e*, were filled with water, and placed under the oil with its mouth or mouths reaching below the water-surface at the level *W*, it would remain full of water, owing to the pressure of the oil surrounding it.—For a similar reason, any such vessel or tube, surrounded only by the air, when filled with water, and placed with its mouth or mouths under the surface of water, remains full; and if such a bent tube has one of its

ends in another vessel lower than the first, a current is established in it;—the contrivance being then called a *syphon*.

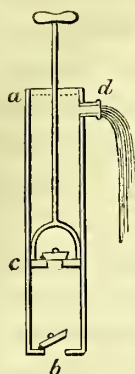
6th. A fish in the water below the level W, would be bearing the pressure of the oil from O to W, as well as the pressure of the water.—So a fish in water open to the air, is bearing the atmospheric pressure of *fifteen pounds per inch*, in addition to that of the water itself. This is proved by extracting the air from over water in which a fish is swimming: for then the air-bag of the fish, situated near its under side, as already described, immediately dilates and turns the fish upon its back.

7th. To separate the Magdeburgh hemispheres, or to produce a vacuum in any way, under the water-level W, would require force proportionate to the weight of oil above, in addition to that required on account of the water:—and to separate the Magdeburgh hemispheres under any water-surface pressed upon by the atmosphere, a force is required of *fifteen pounds per inch* beyond what would balance the effect of the water itself.

The following remarks illustrate more minutely some of the objects which we have just been explaining.

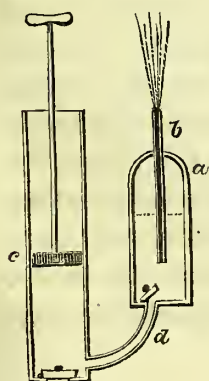
The common *lifting-pump* (or *sucking-pump* as it used to be called), is then merely a barrel *a b*, with a close-fitting moveable plug or piston in it *c*. When the lower end *b* is plunged into water, and the piston is drawn up from the bottom, the atmosphere being prevented from pressing on the surface





of the water within the tube, the pressure on the surface external to the tube, drives the water up after the piston. That the water which thus rises may not fall again, there is a valve or flap at the lower part of the pump-barrel *b*, which opens only to water passing upwards; and that the piston may be allowed to pass downwards through the water in the barrel, to repeat its stroke, there is in it a similar valve.

The piston, in rising during a second or succeeding stroke, causes all the water above it to run over at the spout *d*.—Formerly a lifting-pump was said to act by *sucking* the water up from the well beneath it; the true meaning of which phrase we now perceive to be, that the piston merely lifts or holds off the air which was pressing on the water within the barrel, and allows the water to rise there in obedience to the external pressure of the air around. The reason is apparent then, why, in the lifting-pump, the water will only follow the piston to a certain elevation, *viz.* until its weight balances the external pressure of the atmosphere.

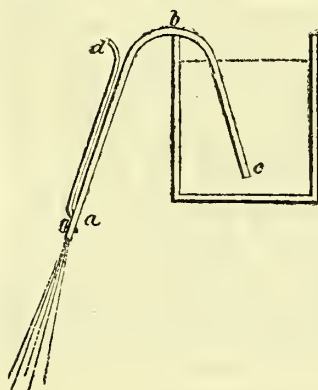


When the piston of a pump is solid, or without a valve, as at *c*, the machine is called a *forcing-pump*. The water rises beneath the piston, as already explained for the lifting-pump, but then, as it cannot pass through the descending piston, as in the lifting-pump it is forced into any other desired

direction, as to *d*. A forcing-pump can bring water from only thirty-four feet below the piston, but can send it to any elevation. In forcing-pumps, it is usual to make the water enter an air-vessel *d a* (already explained at page 332), from which it is again urged by the elastic air, through the pipe *b*, in a nearly uniform stream.

The animal action of *sucking* is an approximation to what we have described in the lifting-pump. The difference is, that the chest or mouth can make only a partial vacuum, and therefore cannot raise a liquid very far.

A *syphon* remains full of liquid, although par-



tially raised above the general surface of the liquid, as explained above. For common purposes, a syphon is made of the form here represented, viz. a bent tube *c b a*, with one end longer than the other. To use it, the end *c* is first immersed in liquid, and the end *a*

being then stopped for the time by the finger or a cock, the air is extracted by the mouth or otherwise, through the small tube *a d*, and the atmosphere immediately fills the whole tube with liquid from *c*. If the instrument be then left to act, the liquid will run from the longer leg, because a long column of liquid overbalances a short one, until the shorter has drunk up all within its reach. Whether the external extremity be in the air only,

or immersed in liquid, makes no difference, except that the immersion shortens so much the descending column. If both extremities be immersed in liquid, and in different vessels, by alternately lifting one vessel or the other, the liquid will be made to pass and repass, and will come to rest in the syphon only when the surfaces in the two vessels are at the same level. Thus the same leg becomes alternately the long and the short leg, according to the height of the liquid in which it is immersed. A syphon is sometimes made with



both legs equal and turned up, as here represented, so that it remains full of liquid although lifted away from the vessel, and therefore is always ready for action. As it is the same cause which lifts the water in a pump and in a syphon, the top of a syphon must evidently be within thirty-four feet of the water-surface below. In the syphon, as in the cases of balancing liquids, described at page 291 (which see), the comparative diameters of the legs is of no importance, nor their oblique length, provided the perpendicular heights of the two columns have the necessary relation:—even an inverted tea-pot may be used as a syphon. This truth is well exemplified in what may be called the *syphon-paradox*, an exact counterpart of the paradox of the “Hydrostatic Bellows,” already explained. If the apparatus of the bellows be filled with water in the ordinary way (see page 258), and be then reversed or turned so that the tube becomes like the long leg of a syphon, the little stream of water issuing from it at *a* will

lift as great a weight suspended *from* the board *d*, as the same slender column in the standing position can lift *upon* the board. As farther illustrative of the atmospherical pressure exerted in producing this effect, and in rendering a syphon active, we may advert to the striking fact, that a long small tube of water screwed into the side or bottom of a close cask of water so as to communicate with it, and then allowed to discharge like the long leg of a syphon, will cause the cask to be crushed inwards, just as the same tube screwed into the top of the cask, as represented at page 257, causes the cask to be burst outwards.

The syphon is very useful for drawing off liquids, where there is a sediment that should not be disturbed, or where it is desirable not to make an opening in the lower part of the vessel. A large syphon would empty a lake or mill-pond over its bank without injuring the bank. To fill a large syphon that it may act, the most convenient way is, instead of pumping out the air from it, to close the two ends for the time, and to pour in water through a cock at the top.

There is a pretty syphon-toy, called a Tantalus' cup, having in it a standing human figure which conceals a syphon. The short branch of the syphon rises in one leg of the figure to reach the level of the chin, and the long branch descends in the other leg to pierce the bottom of the cup towards a reservoir below. On pouring water into the cup, the syphon begins to act as soon as the water reaches the chin of the figure, and the cup is then emptied as if by magic.



Among the infinitely varied water-drains or courses in the bowels of the earth, some are syphons, and produce what are called intermitting wells or fountains. These may alternately run and cease for longer or shorter periods, according to the comparative magnitudes of the collecting reservoir and the drain. The reservoir may be an internal cave of a mountain, receiving a regular supply of water by a slow filtering of moisture from above, and the drain is a syphon-formed channel, which, like that of the Tantalus-cup, begins to act only when the water in the reservoir has reached the level of the top of the syphon, and then carries off the water faster than it is supplied. There are some fountains that flow constantly, but at regular intervals have a remarkable increase. In them a common spring is joined with a syphon-spring.

The author has suggested an application of the syphon, which obviates a strong objection to the high operation for stone, as explained in the next medical section.

The following facts have close relation to those now explained, as further illustrative of atmospheric pressure on liquids.

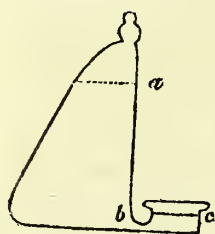
A long glass of jelly, if inverted and placed with its mouth just under the surface of warm water, will soon be found to have lost the jelly, but to be full of water in its stead. The jelly is heavier than water, and when melted by the heat sinks down, and is replaced by water from below, sent up by the atmospheric pressure.

(1.)

Q A

The slaves in the West-Indies steal rum, by inserting the long neck of a bottle full of water through the top aperture of the rum-cask. The water falls out of the bottle into the cask, while the lighter rum ascends in its stead.

The common water-glass for bird-cages has its only opening near the bottom through the neck *b* ;



yet no water can escape from it but when the level of the water at *c*, in the open part, becomes low enough for some air to pass into the body of the glass by the channel *b*. When a bubble of air does pass in, an equal bulk of water comes out, and by raising the water level in *c*, prevents the passage of more.—An ink-glass made on this principle preserves the ink well, because there is so small a surface exposed to the air; if made too large, however, the accidental expansion of the air in it by heat may cause it to overflow.

In the common *Argand* or *fountain-lamp*, the provision of oil is in a vessel like an inverted bottle, higher than the flame, and with its mouth immersed in a small reservoir of oil, nearly on a level with the flame, then no oil can escape from above but as the flame consumes the free oil from the small reservoir, which supply is thus maintained always at the same elevation.—In the Hiero's fountain-lamp, mentioned at page 341, that the two balancing columns of oil may be always of the same height, the oil is supplied to them from high reservoirs, with the mouths dipping into them

as above described, and keeping their tops, therefore, always at the same level ; and that the descending column may not be shortened by the rising of the oil in the low reservoir *c*, the tube containing it is turned up at the bottom like an end of the “ ever ready syphon,” and discharges near the top of *c*.

We have hitherto been contemplating only the direct weight or downward pressure of the atmosphere on liquids : in the following instances we have proof of the same pressure acting upon them in all directions.

If a bottle or cask be filled with liquid, and closely corked, and if a small hole be then drilled in the bottom or side, the liquid will not escape by it, because of the resisting pressure of the atmosphere, and of there not being room in the opening for a current of air to enter while the current of water escapes : but if a second hole be drilled in the top, a jet from the lower opening will follow immediately, because then the air will press on the upper surface of the liquid as well as on the lower, and the weight of the liquid will be free to act :—thus, a cask of beer or wine cannot be emptied by a cock near the bottom, unless what is called a *vent-hole* be made at the top. If the lower opening, however, in any case be so large, that the air may enter by one side of it, while the liquid is escaping by the other, the vessel may be emptied by it, as is seen in decanting a bottle of wine. In such a case it is the interrupted entrance of the air which causes that guggling sound so

delightful to the ear of the drunkard, instead of allowing the smooth stream which falls from a funnel.

Even a large opening at the bottom of a vessel which is close above, may be prevented, by the pressure of the air, from discharging liquid, if any mutual passing of the two currents of air and liquid be rendered difficult. An inverted bottle of water will not discharge, if a piece of paper be simply applied against its mouth. Even a wine-glass filled with water may be inverted, and yet will spill none, if the piece of paper, laid loosely upon its mouth, be held to it during the turning, —the pressure of the atmosphere against the paper keeping it in its place, and supporting the water above it. Any vessel or tube of water, of less height than thirty-four feet, may be kept closed at the bottom in the same way.

*The animal body* is made up of solids and fluids, and is affected by the atmospheric pressure accordingly.

There is difficulty at first in believing that a man's body should be bearing a pressure of fifteen pounds on every square inch of its surface, while he remains altogether insensible of it ; but such is the fact, and the reason of his not feeling the fluid pressure is its being perfectly uniform all around. If a pressure of the same kind be even many times greater, such, for instance, as fishes bear in deep water, or as a man supports in the diving-bell, it equally passes unnoticed. Fishes are at their ease in a depth of water where the pressure around



will instantly break or burst inwards almost the strongest empty vessel that can be sent down ; and men walk on earth without discovering a heavy atmosphere about them, which, however, instantly crushes together the sides of a square glass bottle emptied by the air-pump, or even of a thick iron boiler, left for a moment by any accident, without the counteracting internal support of steam or air.

The fluid pressure on animal bodies, thus unperceived under ordinary circumstances, may be rendered instantly sensible by a little artificial arrangement. In water, an open tube partially immersed becomes full to the level of the water around it, and the water contained in it is supported, as already explained, by that which is immediately below its mouth : now a flat fish resting closely against the mouth of the tube, would evidently be bearing on its back the whole of this weight, perhaps one hundred pounds ; but the fish would not thereby be pushed away, nor would it even feel its burden, because the upward pressure of the water immediately under it would just counterbalance the weight, while the lateral pressure around would prevent any crushing effect of the upward and downward forces. But if, while the fish continued in the situation supposed, the hundred pounds of water were suddenly lifted from off its back by a piston in the tube, the opposite upward pressure of one hundred pounds would at once crush its body into the tube. At a less depth, or with a smaller tube, the effect might not be fatal, but there would be a bulging or swell-

ling of the substance of the fish into the mouth of the tube.—In air and on the human body a perfectly analogous case is exhibited. A man without pain or any peculiar sensation, applies his hand closely to the mouth or opening of a tube, or of any vessel containing air, but the instant that the air is withdrawn from within the tube or vessel, the then unresisted pressure of the external air fixes the hand upon the opening, causes the flesh to swell or bulge into it, and makes the blood ooze from any crack or puncture in the skin.

These last lines describe closely the surgical operation of *cupping*; the essential circumstances of which are, the application of a cup or glass, with a smooth blunt lip, to the skin of any part of the body, and the extraction by a syringe or other means, of a portion of the air from within the cup. To some minds the exact comprehension of this phenomenon may be facilitated, by considering the case of a small bladder or bag of India-rubber full of any fluid and pressed between the hands on every part of its surface except one:—at that one part it would swell, and even burst if the pressure were strong enough. So in cupping, the whole body, except the surface under the cup, is squeezed by the atmosphere, with a force of fifteen pounds to the square inch, while in that one situation the pressure is diminished according to the degree of exhaustion in the cup, and the blood consequently accumulates there. The application of a cup with exhaustion only, constitutes the operation called *dry-cupping*. To obtain blood, the cup is removed and the tumid

part is cut into by the simultaneous stroke of a number of united lancets : and the cup is then applied again as before and exhausted, so that the blood may rush forth under the diminished pressure. The partial vacuum in the cup may be produced either by the action of a syringe, or by burning a little spirit in the cup and applying it while the momentary dilatation effected by the heat has driven out the greater part of the air. The human mouth applied upon any part becomes a small cupping apparatus, and formerly, in cases of poisoned wounds, was used as such. Our present perfect cupping glasses, of stronger and more permanent operation, are not yet always used, as they might be, to assist in removing the poison after the bites of rabid or venomous animals.

The author has suggested an extension and modification of the operation of dry cupping, which he believes will prove an important remedy in the hands of the medical practitioner. It is intended as a substitute for bleeding, in certain cases where blood can ill be spared, and as a more sudden and effectual check than even bleeding itself, in certain cases of inflammatory disease. It is explained in the next medical section of this work.

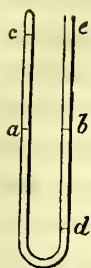
The atmospheric pressure on living bodies produces an effect which is rarely thought of, although of much importance, *viz.* keeping all the parts about the joints firmly together, by an action similar to that exerted on the Magdeburgh hemispheres. The broad surfaces of bone forming the knee joint, for instance, even if not held together by ligaments, could not, while the capsule surrounding

the joint remained air-tight, be separated by a force of less than about a hundred pounds ; but on air being admitted to the articular cavity, the bones at once fall to a certain distance apart. In the loose joint of the shoulder, this support is of great consequence. When the shoulder or other joint is dislocated, there is no empty space left, as might be supposed, but the soft parts around are pressed in, to fill up the natural place of the bone. When a thigh bone is dislocated, the deep socket called the acetabulum instantly becomes like a cupping-glass, and is filled partly with fluid and partly with the soft solids. In all joints it is the atmospheric pressure which keeps the bones in such steady contact, that they work smoothly and without noise.

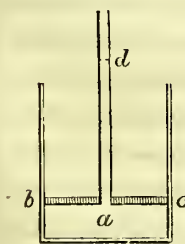
*The barometer*, we have seen at page 353, is a column of fluid supported in a tube by the pressure of the atmosphere, and therefore indicating most exactly the degree of that pressure. It is an instrument now of such importance, both in a scientific point of view and in the business of common life, that for the sake of minds which conceive such subjects with difficulty we shall add here the two following further illustrations of its nature.

If mercury be poured into a bent tube open at both ends, it will stand at the same level in the two legs, as at *a* and *b*, and the air will be pressing on the two surfaces at *a* and *b* with equal force of 15lb. per square inch. If the air be then removed from one leg *a*, by a piston or otherwise,





while it continues to press in the other leg *b*, the mercury will be pushed down in *b*, until the growing height of the column in *a* produces a weight so much greater than that in *b*, as just to counteract the pressure: now this balance takes place, in fact, when the mercury in *a* stands about thirty inches higher than in *b*: that being the height of a column of mercury weighing 15lbs. on the square inch. If the top of the tube *a* were then closed permanently, the mercury would for ever remain elevated in it, marking most perfectly the atmospheric pressure: now this construction, only with the empty and useless part of the tube above *d* cut off or wanting, forms a common barometer. The exact altitude of the mercury in it is known by observing how much the surface near *c* is higher than that near *d*. Often, in such a barometer, a little mass of metal is placed to float on the mercurial surface at *d*, and as it rises and falls, is caused, by a thread passing from it over a wheel or pulley, to move an index like the hand of a clock connected with the wheel, and this index tells the degree of elevation. This modification is called the *wheel barometer*.



Again, as water at *a*, in the bottom of a closed pump-barrel, if pressed upon by the piston *b* *c*, of which the rod *d* were hollow or tubular, would rise in the rod to a height proportioned to the pressure made by the piston: so, in a straight exhausted

barometer-tube, which is as this hollow piston-rod, the mercury or water rises, because the atmospheric pressure around it is as the piston forcing the fluid up. To make a barometer of this kind it is only necessary to procure a glass tube more than thirty inches long, and close at one end, and then having filled it with mercury, to plunge its mouth (stopped by the finger while turning) into a small cup or basin of mercury :—the fluid falls away a little from the top of the tube, leaving a vacuum there, and stands at the elevation which the atmospheric pressure is fitted to maintain. We know, from the law of hydrostatics already explained, that it is of no importance, in such a case, what the shape, or inclination, or size of the tube may be, as only the perpendicular height can measure or be measured by the pressure. This fact enables us to construct barometers with the upper part of the tube bent obliquely, so that for one inch rise of mercury in a perpendicular tube, there shall be an advance of several inches in the oblique top, rendering any change of elevation so much more apparent.

Galileo had found that water would rise under the piston of a pump to a height only of about thirty-four feet. His pupil Torricelli, conceiving the happy thought, that the weight of the atmosphere might be the cause of the ascent, concluded that mercury, which is about thirteen times heavier than water, should only rise under the same influence to a thirteenth of the elevation :—he tried and found that this was so, and the mercurial barometer was invented. Pascal then, to afford fur-

ther evidence that the weight of the atmosphere was the cause of the phenomenon, carried the tube of mercury to the tops of buildings and of mountains, and found that it fell always in exact proportion to the portion of the atmosphere left below it ;—and he found that water-pumps in different situations varied as to sucking power, according to the same law.

It was soon afterwards discovered, by careful observation of the mercurial barometer, that even when remaining in the same place, it did not always stand at the same elevation ; in other words, that the weight of atmosphere over any particular part of the earth was constantly fluctuating ; a truth which, without the barometer, could never have been suspected. The observation of the instrument being carried still farther, it was found, that in serene dry weather the mercury generally stood high, and that before and during storms and rain it fell :—the instrument therefore might serve as a prophet of the weather, becoming a precious monitor to the husbandman or the sailor.

The reasons why the barometer falls before wind and rain will be better understood a few pages hence ; but we may remark here, that when water which has been suspended in the atmosphere, and has formed a part of it, separates as rain, the weight and bulk of the mass are diminished : and that wind must occur when a sudden condensation of aeriform matter, in any situation, disturbs the equilibrium of the air ; for the air around will rush towards the situation of diminished pressure.

To the husbandman the barometer is of considerable use, by aiding and correcting the prognostics of the weather which he draws from local signs familiar to him; but its great use as a weather-glass seems to be to the mariner, who roams over the whole ocean, and is often under skies and climates altogether new to him. The watchful captain of the present day, trusting to this extraordinary monitor, is frequently enabled to take in sail and to make ready for the storm, where, in former times, the dreadful visitation would have fallen upon him unprepared.—The marine barometer has not yet been in general use for many years, and the author of this work was one of a numerous crew who probably owed their preservation to its almost miraculous warning. It was in a southern latitude; the sun had just set with placid appearance, closing a beautiful afternoon, and the usual mirth of the evening watch was proceeding, when the captain's order came to prepare with all haste for a storm. The barometer had begun to fall with appalling rapidity. As yet, the oldest sailors had not perceived even a threatening in the sky, and were surprised at the extent and hurry of the preparations: but the required measures were not completed, when a more awful hurricane burst upon them than the most experienced had ever braved. Nothing could withstand it; the sails already furled and closely bound to the yards, were riven away in tatters: even the yards and masts themselves were in great part disabled; and at one time the whole had nearly fallen by the board. Such, for a few hours,



was the mingled roar of the hurricane among the rigging, of the waves around, and of the incessant peals of thunder, that no human voice could be heard, and amidst the general consternation, even the trumpet sounded in vain. In that awful night, but for the little tube of mercury which had given the warning, neither the strength of the noble ship, nor the skill and energies of the commander, could have availed any thing, and not a man would have escaped to tell the tale. On the following morning the wind was again at rest, but the ship lay upon the yet heaving waves, an unsightly wreck.

The marine barometer differs from that used on shore, in having its tube contracted in one place to a very narrow bore, so as to prevent that sudden rising and falling of the mercury, which every motion of the ship would else occasion.

Civilized Europe is now familiar with the barometer and its uses, and therefore, that Europeans may conceive the first feelings connected with it, they almost require to witness the astonishment or incredulity with which people of other countries still regard it. A Chinese once conversing on the subject with the author, could only imagine of the barometer, that it was a gift of miraculous nature, which the God of Christians gave them in pity, to direct them in the long and perilous voyages which they undertook to unknown seas.

A barometer is of great use to persons employed about those mines in which *hydrogen gas*, or *fire-damp*, is generated and exists in the crevices. When the atmosphere becomes unusually light,

the hydrogen being relieved from a part of the pressure which ordinarily confines it to its holes and lurking-places, expands or issues forth to where it may meet the lamp of the miner, and explode to his destruction. In heavy states of the atmosphere, on the contrary, it is pressed back to its hiding-places, and the miner advances with safety.

We see from this that any reservoir or vessel containing air would itself answer as a barometer if the only opening to it were through a long tubular neck, containing a close-sliding plug; for then, according to the weight and pressure of the external air the density of that in the vessel would vary, and all changes would be marked by the position of the moveable plug. A barometer has really been made on this principle by using a vessel of glass, with a long slender neck, in which a globule of mercury is the moveable plug.

The state of the atmosphere, as to weight, differs at different times in the same situation, so as to produce a range of about three inches in the height of the mercurial barometer; that is to say, from twenty-eight to thirty-one inches. On the occasion of the great Lisbon earthquake, however, the mercury fell so far in the barometers, even in Britain, as to disappear from that portion at the top usually left uncovered for observation.—The uncovered part of a barometer is commonly of five or six inches in length, with a divided scale attached to it, on which the figures 28, 29, &c. indicate the number of inches from the surface of the mercury at the bottom to the respective divi-

sions :—on the lower part of the scale the words *wind* and *rain* are generally written, meaning that when the mercury sinks to them, wind and rain are to be expected ; and on the upper part, *dry* and *fine* appear, for a corresponding reason : but we have to recollect, that it is not the absolute height of the mercury which indicates the existing or coming weather, but the recent change in its height :—a falling barometer usually telling of wind and rain ; a rising one of serene and dry weather.

The barometer answers another important purpose, besides that of a *weather-glass*—in enabling us to ascertain readily the height of mountains, or of any situation to which it can be carried.

As the mercurial column in the barometer is always an exact indication of the weight or pressure of air above its level, being indeed, as explained in the foregoing paragraphs, of the same weight as a column of the air of equal base with itself, and reaching from it to the top of the atmosphere, —the mercury must fall when the instrument is carried from any lower to any higher situation, and the degree of falling must always tell exactly how much air has been left below. For instance, if thirty inches barometrical height mark the whole atmospheric pressure at the surface of the ocean, and if the instrument be found, when carried to some other situation, to stand at only twenty inches, it proves that one-third of the atmosphere exists below the level of the new situa-

tion. If our atmospheric ocean were of as uniform density all the way up as our watery oceans, a certain weight of air thus left behind in ascending would mark every where a change of level nearly equal, and the ascertaining any height by the barometer would become one of the most simple of calculations :—the air at the surface of the earth being between eleven and twelve thousand times lighter than its bulk of mercury, an inch rise or fall of the barometer would mark every where a rise or fall in the atmosphere of nearly twelve thousand inches or one thousand feet. But owing to the elasticity of air, which causes it to increase in volume as it escapes from pressure, the atmosphere is rarer in proportion as we ascend, so that to leave a given weight of it behind, the ascent must be greater, the higher the situation where the experiment is made : the rule, therefore, of one inch of mercury for a thousand feet, holds only for rough estimates near the surface of the earth. The precise calculation, however, for any case, is still very easy ; and a good barometer, with a thermometer attached, and with tables, or an algebraical formula expressing all the influencing circumstances, enables us to ascertain elevations much more easily, and in many cases more correctly, than by trigonometrical survey.

The weight of the whole atmospherical ocean surrounding the earth being equal to that of a watery ocean of thirty-four feet deep, or of a covering of mercury of thirty inches, and the air found at the surface of the earth being 828 times lighter than water, if the same density existed all



the way up, the atmosphere would be 34 times 828 feet high, equal to about five miles and a-half. On account of the greater rarity, however, in the superior regions, it really extends to a height of nearly fifty miles. From the known laws of aerial elasticity, explained at page 329, we can deduce what is found to hold in fact, that one-half of all the air constituting our atmosphere exists within three miles and a-half from the earth's surface; that is to say, under the level of the summit of Mont Blanc. A person unaccustomed to calculation, would suppose the air to be more equally distributed through the fifty miles than this rule indicates, as he might at first also suppose a tube of two feet diameter to be only twice as capacious as a tube of one foot, although in reality it is four times as capacious.

In carrying a barometer from the level of the Thames to the top of St. Paul's Church in London, or of Hampstead Hill, the mercury falls about half an inch, marking an ascent of about five hundred feet. On Mont Blanc it falls to half of the entire barometric height, marking an elevation of fifteen thousand feet; and in Du Luc's famous balloon ascent it fell to below twelve inches, indicating an elevation of twenty-one thousand feet, the greatest to which man has ever ascended from the surface of his earthly habitation.

The extreme rarity of the air on high mountains must of course affect animals. A person breathing on the summit of Mont Blanc, although expanding his chest as much as usual, really takes in at each inspiration only half as much air as he does below

—exhibiting a contrast to a man in the diving-bell, who, at thirty-four feet under water, is breathing air of double density, at sixty-eight feet of triple, and so on. It is known that travellers, and even their practised guides, often fall down suddenly as if struck by lightning, when approaching lofty summits, on account chiefly of the thinness of the air which they are breathing, and some minutes elapse before they recover. In the elevated plains of South America, the inhabitants have larger chests than the inhabitants of lower regions—furnishing another admirable instance of the animal frame adapting itself to the circumstances in which it is placed. It appears from all this, that although our atmosphere be fifty miles high, it is so thin beyond three miles and a half, that mountain ridges of greater elevation are nearly as effectual barriers between nations of men, as islands or rocky ridges in the sea are between the finny tribes inhabiting the opposite coasts. The intense cold which appertains to high situations, and forms another obstacle to human approach, remains to be considered in our next division.

A barometer connected with an air-pump, indicates exactly the progress and degree of exhaustion in the receivers. When the mercury falls to half its height, it shews that half of the air is extracted; and so for all other proportions. A barometer then is a necessary appendage to a complete air-pump; but as its chief purpose is to mark when the exhaustion is carried nearly to completion, a very short tube, corresponding to the bottom of a common barometer, is all that is gene-

rally provided, and it is usually made of syphon form.

The ingenious method, mentioned at page 299, of ascertaining the specific gravity of the solid material forming any porous mass or powder, includes the agency of a barometer. It proceeds upon this reasoning. The interstices of a porous or pulverized mass are filled with air of the density of the surrounding atmosphere, and if the atmospheric pressure on which that density depends be diminished upon the mass in any given degree, an exactly corresponding proportion of the air will issue from the pores, and, if measured, will declare the whole quantity, and therefore the amount of interstice or pores in the solid mass. Now if the substance were enclosed at the end or bottom of a syringe, the pressure of the atmosphere might be held off from it in any degree by drawing at the piston, and the air would issue from the pores as described, and would follow the piston; but as, owing to the friction of a solid piston, it would be difficult to measure the precise action, the liquid piston of a mercurial column has been substituted, of which the force is always proportioned to the length. The operator takes an open glass tube, *a e*, of known dimensions, and prepares a part of its top, *a b*, as a receptacle for the substance under trial, by affixing a partition at *b*, which shall support the substance, but allow passage to air. Having then filled *a b* with the substance, he gradually immerses the tube in a vessel of mercury *d f*, until the mercury stand both inside and outside of the tube at the level of *b*, the air from



the tube having passed out through the substance in *a b*. It is evident that on then closing the tube at *a* in an air-tight manner, and lifting the tube, a column of mercury will remain standing in it, above the level of the external mercury at *d*, and will be acting as a piston pulling down from *b* with force proportioned to its height. If the tube be lifted until such mercurial column *c d* be just of half the length of the column in a common barometer, the air in the pores of the substance will be relieved from half of the atmospheric pressure, and will dilate to double bulk; so that while half of the air will remain in the pores, the other half will have issued forth to occupy a space, as *b c*, between the surface of the mercury and the partition at *b*. This space *b c*, therefore, will be exactly equal to the amount of the pores or interstices; and as it may be measured and compared with the whole space *a b*, its ascertained magnitude will solve the problem. It has been found in this way that charcoal, which is usually said to be only half as heavy as its bulk of water, is really formed of matter nearly four times as heavy; proving, in a new way, the identity of charcoal and diamond: and that light pumice-stone consists of matter heavier than granite or marble. This very ingenious application of the barometer may lead ultimately to many useful results; and the contrivance merits consideration here, as exhibiting under a new and interesting aspect the rationale of barometric action and the elasticity of air.



*Atmospheric pressure determining the liquid or aeriform state of certain substances.* (See the Analysis, page 320.)

It has already been stated that the permanent gases—or substances usually in the aeriform state—may be reduced to the liquid, or even solid form, by simple pressure, and abstraction of the heat which is combined with them in the aeriform state. Carbonic acid, the common coal gas, &c. have been treated in this way. Now it becomes an interesting question whether many of the substances known as liquids on the face of the earth, where they are bearing the pressure of the atmosphere, would not appear as airs if that pressure did not exist.

On investigating this subject by experiment, we accordingly find, that *æther*, *alcohol* or *ardent spirits*, *volatile oils*, &c., and even *water* itself, are known to us here as liquids, only because their particles are kept together by the weight and pressure of a superincumbent atmosphere. Any of these substances, relieved by art from such pressure, quickly becomes an air or gas, just as a common gas, which has been kept in the state of liquid by any great pressure, becomes air again on being relieved.

In our first chapter we explained the dependence of the three forms which any body may assume, *viz.* of solid, liquid, or air, on the quantity of heat diffused among the particles : we now see, however, that to understand the subject completely, we must consider also the effect of accidental pressure; for, while heat is the power separating the atoms

in the changes mentioned, it has to overcome both the mutual attraction of the atoms and the additional force of the atmosphere pressing them together. The combined influence of these forces is fully displayed in the two phenomena called *boiling* and *evaporation*, which exhibit the progress of the change of a liquid into an aeriform fluid. We now proceed to examine these phenomena.

*Boiling.*—If water be placed in a suitable vessel over a common fire, or over the flame of a lamp, it is gradually heated to a certain degree; and then small bubbles of aeriform matter, *viz.* water, in the state called steam, are seen forming at the bottom of the vessel, and successively rising to the surface, where they disappear by mixing with the atmosphere; and the operation being continued, the quantity of water diminishes with every bubble, until the whole vanishes under the new form of air.

This change takes place in water, under common circumstances, at the degree of heat marked  $212^{\circ}$  on Fahrenheit's thermometer, and called on that account the *boiling point* of water; at which, therefore, the repulsive power among the particles is just sufficient to overcome both their natural attraction, and the compressing force of the atmosphere of fifteen pounds on the inch. But a less degree of heat suffices if the pressure of the atmosphere be lessened or removed; and a greater degree is required if pressure be increased. Water on the top of Mont Blanc boils at  $180^{\circ}$ , because relieved from the pressure of the air that is below the level of the mountain's summit; and at all

intermediate heights in descending to the level of the sea, and beyond that into mines, there is a corresponding increase of the boiling temperature. So exactly is this the case, that we now find it to be a good method of ascertaining the heights of places, merely to observe the heat of boiling water at them. To many persons the information here given that boiling water is not equally hot in all places, will appear extraordinary: and they will now understand, that even in the same place, at different times when the barometer is high or low, there will be corresponding differences.—Again, near the bottom of a boiler, the water is hotter than above, because it is bearing an additional pressure proportioned to the depth, and does not therefore give out the steam which it would part with if a little higher up. In very large and deep boilers, therefore, such as are used in great porter breweries, the liquor is much more heated than it can be in smaller vessels;—a circumstance which probably has an influence on its ultimate quality.

While water under common atmospheric pressure, or when the barometer stands at thirty inches, boils at  $212^{\circ}$ , other substances, with other relations to heat, have their *boiling points* higher or lower:—æther, for instance, at  $98^{\circ}$ ; spirit or alcohol at  $174^{\circ}$ ; fish-oil and tallow at about  $600^{\circ}$ ; mercury at  $650^{\circ}$ .

It is in consequence of the different temperatures at which the particles of different substances acquire repulsion enough to rise against the atmospheric resistance, that we are enabled to perform the operation called *distilling*. If a mixture of

spirits and water, for instance, be heated up to  $180^{\circ}$ , the spirit will pass off in the aeriform state, leaving the water behind, and may be caught apart and cooled to condensation in any fit receiver. Distillation is the best means we possess of separating many substances from each other : as spirit from wine or other fermented liquor ; various acids from water ; water itself from its common impurities ;—and even the separation of mercury from silver or gold which it has been used to dissolve from among the rubbish of a mine or river-bottom, is merely a distillation.

We must call to mind here what was mentioned in a former part of the work, that a large quantity of heat combines with every substance during the change of form from solid to liquid, or from liquid to air ; a quantity which, from not remaining sensible to the thermometer, has received the name of *latent* or *concealed heat*. The whole of this is given out again in the contrary change. In the conversion of water into steam, the heat which thus disappears is about 1,000 degrees, or six times as much as is required to raise the cold water to the boiling point : this is proved by the time and fuel expended in boiling any quantity to dryness, and by the fact that a pint of water in the form of steam will combine instantly with six pints of cold water, raising the whole to boiling heat.

But for the fact of latent heat, the conversion of a liquid into air would not be the gradual process of boiling which we now see, but a sudden and terrible explosion : for when any quantity of water were raised to the boiling heat, one degree more



would be sufficient to convert the whole into steam. And but for the same reason, the thawing of winter snow would always be a sudden and frightful inundation; the whole load of a mountain or plain becoming at once as a lake bursting from its enclosing barriers. On the other hand, if water in freezing had not to give out again its latent heat, after any quantity were once cooled down to the freezing point, the abstraction of one degree more would instantly convert the whole into a solid mass. Thus, then, by an arrangement effecting most important purposes in nature and art, all changes from solid to liquid and from liquid to air, and the converse changes, are very gradual.

If a little heat be abstracted from steam, a part of the steam proportioned to the abstraction is immediately condensed into water. What is called steam in common language—as the vapour which becomes visible at a little distance from the spout of a boiling kettle or the chimney of a tea-urn—is not truly *steam*, but small globules of water already condensed by the cold air and mixed with it. Steam is as dry and invisible as air itself; but the instant that it comes in contact with air or other bodies colder than itself, it becomes water.

By means of the exhausting air-pump on one hand, and of the condensing syringe on the other, all the above-mentioned phenomena, depending on the atmospheric pressure, and its increase or diminution, may be strikingly shewn.

Thus, to exhibit the effect of diminished pressure, water not heated by several degrees to the

boiling point of ordinary low situations but which would be boiling at the top of Mont Blanc, is caused to boil instantly by placing it under the receiver of an air-pump, and making a few strokes of the piston; if the exhaustion be rendered nearly complete, the water will boil, even when colder by  $20^{\circ}$  than the blood of animals; and at degrees of temperature still much lower, it will rapidly assume the form of air, although not with force sufficient to produce the violent agitation of boiling. Other liquids, as spirits, æther, &c., from requiring inferior degrees of heat to separate their particles to aeriform distances, boil under the receiver of an air-pump at very low temperatures; æther, for instance, when as cold as freezing water.

On the other hand, to exhibit the effect of increased pressure, if we confine the particles of a liquid still more than by a common atmospheric or equivalent pressure, degrees of heat higher than the common boiling point will be required to separate them. In a diving-bell, the boiling point of water is higher than  $212^{\circ}$  in proportion to the depth which the bell has reached: and if at the surface of the earth, we heat water in a close vessel into which air is forced so as to press thirty pounds on the inch instead of fifteen, as the atmosphere does; or from which we prevent the steam's escaping until it has acquired the force of a double atmosphere,—before making the liquid boil we shall have to raise the heat, in a corresponding proportion beyond  $212^{\circ}$ . Under a very strong pressure, water may be rendered almost red-hot, but the force with which its particles are

then tending to separate is almost that of inflamed gunpowder. Even then, however, if a gradual issue were allowed, only a certain quantity of the water would absorb and render latent the existing excess of heat above  $212^{\circ}$  and would become common steam, leaving behind a considerable portion as boiling water of the ordinary temperature.

The fact that liquids are driven off, or made to boil at lower degrees of heat when the atmospheric pressure is lessened or removed, has recently been applied to some very useful purposes.

The process for refining sugar is to dissolve impure sugar in water, and after clarifying the solution, to boil off or evaporate the water again, that the dry crystallized mass may remain. Formerly this evaporation was performed under the atmospheric pressure, and a heat of  $218^{\circ}$  or  $220^{\circ}$  was required to make the syrup boil; by which degree of heat, however, a portion of the sugar was discoloured and spoiled, and the whole product was deteriorated. The valuable thought occurred to Mr. Howard, that the water might be dissipated by boiling the syrup in a vacuum, or at least a place from which air was nearly excluded, and therefore at a low temperature. This was done accordingly; and the saving of sugar and the improvement of quality were such, as to make the patent-right, which secured the emoluments of the process to him and other parties, worth many thousand pounds a year. The syrup, during this

process, is not more heated than if in a vessel merely exposed to a summer sun.

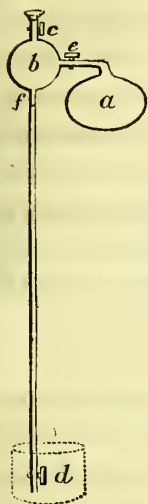
In the preparation of many medicinal substances, the process of boiling *in vacuo* is equally important. Many extracts from vegetables have their virtues impaired, or even destroyed, by a heat of  $212^{\circ}$ ; but when the water used in making the extract is driven off *in vacuo*, the temperature need never be higher than blood-heat, and all the activity of the fresh plant remains in the extract.

In the same manner, in the process of distillation,—which is merely the receiving and condensing again in appropriate vessels the aeriform matter raised by heat from any mass,—substances which are changed and injured by an elevated temperature, may be obtained of admirable quality by carrying on the operation in a vacuum. The essential oils of lavender, peppermint, &c. never had the natural flavour and virtues of the plants until within the last few years, since this plan has been adopted.

The influence on the human system of vegetable medicines obtained in the old or in the new way, is so different, that the prescriber should carefully advert to the circumstance.

The apparatus for evaporating and distilling *in vacuo* consists of vessels strong enough to bear, when quite empty, the external atmospheric pressure, and which are therefore generally of arched form. The vacuum is produced and maintained by air-pumps driven by a steam-engine or otherwise; or by first admitting steam to expel the air, and then condensing the steam into water.





The author has suggested a very simple contrivance to answer in certain cases the purpose of such air-pumps and steam-engines or apparatus. It is merely to establish a communication between a close boiler, as *a*, and the vacuum at the top of a water-barometer, as *b*. To produce that vacuum, the strong vessel *b* forming the top of the barometer, and thirty-six feet of tube below, reaching to *d*, are first filled with water through a cock *c* at the top; this cock being then shut, and another cock *d* at the bottom, which was shut, being opened, the water will sink down out of the vessel *b*, until the column in the tube be only thirty-four feet high, as at *f*, that being the height which the atmosphere will support. On then opening a communication between the boiler *a* and the vacuum in *b*, the operation will go on as desired, and the steam rising from *a* may be condensed in *b* by a little stream of cold water allowed constantly to run through from above. This water, it is evident, would always pass downwards to form part of the column below, without filling up or impairing the vacuum. If air should find admittance in any way, the original degree of vacuum could easily be reproduced as at first; and to prevent interruptions, it might be convenient to have two vessels like *b*, of which one could always be in action while the other were being emptied of air. The author planned this as a simple apparatus for the preparation of medicinal extracts; and it

appears well suited also for the manufacture of sugar in the colonies, where air-pumps and nice machinery can with difficulty be either obtained or managed. On many sugar estates there is a fall of water, which would supply the barometer without the trouble of pumping. The tube *d c* needs not be perpendicular, provided it be longer in proportion to its obliquity; and it may be very small: some yards of common lead-pipe would answer.

WHEN it was understood that, at common temperatures, water and many other liquids would be existing in the form of air, but for an atmospheric pressure opposing the separation of the particles, it became of great importance in many of the arts, and for comprehending certain phenomena of nature, to ascertain, very exactly, with respect to some of these liquids, the degrees of expansive force belonging to them at different degrees of temperature. The subject, as water is concerned, has been investigated with great care, and the following table shews part of the results. The left-hand column marks temperatures from  $32^{\circ}$  of Fahrenheit's thermometer, or the freezing point of water, to  $290^{\circ}$ ; and the right-hand column marks the corresponding degrees of force with which the water tends to expand into the state of steam, and therefore also the force and density of the steam existing in any vessel above the water which it contains. One ounce and a half per square inch, is the force exerted on the sides of any containing vessel by steam rising from freezing water, that is

to say, the force with which freezing water seeks to dilate into steam or air; and sixty pounds per inch is the force of water heated to  $290^{\circ}$ . To many readers the idea will be quite new and surprising, that if some freezing water, or even ice, be placed in a bladder containing nothing else, and the bladder be then placed in the exhausted receiver of an air-pump or other vacuum, the bladder will quickly be distended with steam strong enough to support one ounce and a-half on every square inch of its upper surface.

At $32^{\circ}$ force of steam is	$1\frac{1}{2}$ oz. per inch.
50 .....	$2\frac{3}{4}$ oz.
100 .....	13 oz.
150 .....	4 lbs.
180 .....	$7\frac{1}{2}$ lbs.
212 .....	15 lbs.
250 .....	30 lbs.
272 .....	45 lbs.
290 .....	60 lbs.

In this table we have to remark how much more rapidly the tendency to become steam increases than the temperature of the water: for a rise of eighteen degrees, *viz.* from  $32^{\circ}$  to  $50^{\circ}$ , at the beginning of the scale, only increases the dilating force *one ounce and a quarter* on the inch, while an equal rise at the top of the scale, *viz.* from  $272^{\circ}$  to  $290^{\circ}$ , increases it *fifteen pounds*. It is most important to distinguish, however, between the *tendency to form steam* at any temperature, and the *bulk or quantity of steam* formed by a given quantity of heat; for the matter imperfectly understood has

led to many vain schemes for improving the *steam-engine*. The truth is, that *high-pressure steam* is merely *condensed steam*, as *high-pressure air* is *condensed air*; in other words, the density of steam is greater, or there must be more of it, exactly as its force is greater, according to the rule explained at page 329 ; and the heat absorbed in its formation being proportioned to the quantity of steam in a given space, or the density, the force and the cost in fuel have always nearly the same relation to each other. In one pint of steam at  $290^{\circ}$ , having an elastic force of sixty pounds on the inch, there is very nearly four times as much water and four times as much latent heat as in one pint of steam at  $212^{\circ}$ , which has a force of fifteen pounds on the inch,—indeed, the one pint at  $290^{\circ}$  may be changed into the four pints at  $212^{\circ}$ , or the contrary, by merely changing the degrees of pressure. It does not accord with the plan of the present work to enter farther into the details of this subject, but they may be found in various modern treatises.

Seeing the rapid increase of the expansive force in the above table, we have the explanation of the terrible effects occasionally produced by confined water when overheated. A boiler of any kind, completely closed, and having no safety valve, if heated to a certain degree, will explode as if charged with gunpowder. Unhappily the instances are too numerous where the incautious or ignorant use of steam has produced explosions, which have shattered buildings and destroyed whole neighbourhoods.

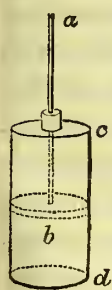


The prodigious force generated by heating water would at first only surprise and terrify men, but in the course of time would lead inventive minds to inquire whether it might not be turned to use; in other words, whether some mechanism, to be called a *steam-engine*, might not be contrived to enable men to make it aid them in their various labours. To this inquiry, after numerous less successful attempts, a glorious answer has been given in our own day by the illustrious WATT;—and to this part of our work it belongs to consider what he has accomplished, *viz.* to describe

### *The Steam-Engine,*

which in the few years since the genius of WATT carried it to its present state of perfection, has changed the direction of human industry, and may almost be said to have elevated man in the scale of existence.

The name of *steam-engine*, to most persons, brings the idea of a machine of the most complex nature, and hence to be understood only by those who will devote much time to the study of it; but he who can understand a common pump, may understand a steam-engine. It is in fact only a



(1.)

pump in which the fluid passing through it is made to impel the piston instead of being impelled by it, that is to say, in which the fluid acts as the *power* instead of being the *resistance*. It may be described simply as a strong barrel or cylinder *c d*, with a closely fitting piston in it, here shewn at *b*, which is driven up

2 c

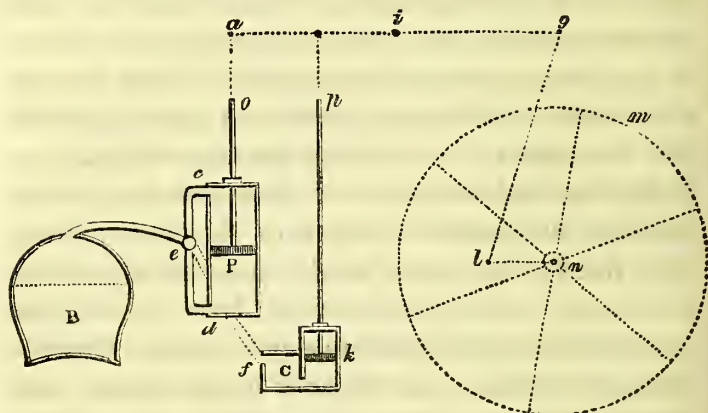
and down by steam admitted alternately above and below it from a suitable boiler; while to the end of the piston rod *a*, at which the whole force may be considered as concentrated, there is attached in any convenient way the work which is to be performed. The power of the engine is of course proportioned to the size or area of the piston, on which the steam acts with a force, according to its density, of from 15 to 100 or more pounds to each square inch. In some of the Cornish mines there are cylinders and pistons of more than ninety inches in diameter, on which the pressure of the steam equals the effort of six hundred horses.

In one place this wonderful piston-rod may be seen acting upon the end of a great vibrating beam, to the other end of which capacious water-pumps are attached, whose motion causes almost a river to gush up from the bowels of the earth. In another place, it is seen working a crank, and urging complicated machinery. One steam-engine four miles from London is at the same instant filling all the water reservoirs and baths and fountains of the finest quarter of the town. One engine, stretching long arms over a great barrack or manufactory, keeps in one quarter, thousands of spinning-wheels in motion, while in another it is carding the material of the thread, and in another weaving the cloth. In like manner, one steam-engine in a great metropolitan brewery may be seen at the same time grinding the malt, pulling up supplies of all kinds from waggons around the building, pumping cold water into some of the

coppers, sending the boiling wort from others up to lofty cooling-pans, over which it is turning the fans, perhaps also working the mash-tub, drawing water from the deep wells under ground, and loading the drays—in a word, performing the offices of a hundred hands. Again, there are manufactories where this resistless power is seen with its mechanic claws seizing masses of iron, and in a few minutes delivering them out again pressed into thin sheets, or cut into bars and ribands, as if the iron had become to it like soft clay in the hands of the potter. And now for some years, over nearly the whole world, has this wonderful piston-rod, working at its crank, been turning the paddle-wheels of innumerable steam-boats, thereby setting at defiance the violence of the winds and waves, and the currents of the fleetest rivers, while it carries men and civilization into the remote recesses of all the great continents. To wherever a river leads, the region, although concealed perhaps since the beginning of the world, is now by the steam-engine called as it were from its solitude, to form a part of the great garden which civilized man is beautifying.—Such are a few of the prodigies which this machine is already performing, and every day is witnessing new applications of its utility.

The following account of the parts of the steam-engine is intended, without entering into minute practical details, still fully to explain the principle or general nature of the machine. It should serve to render very interesting to an attentive reader, a visit to any place where a steam-engine

is in use ; and it should make evident the folly of many of the modern schemes for improving the engine. To avoid complexity in the figure, the parts which the reader can easily conceive are not here sketched.



1st. The part which first claims attention is the great *barrel* *c d*, already spoken of as the centre or main portion of the machine, in which the *piston* *P* is moved up and down by the action of steam entering alternately above and below it, through the pipes *e c* and *e d*. The barrel or cylinder is bored with extreme accuracy, and the piston is padded round its edge with hemp or other soft material, so as to be perfectly air or steam-tight. Lately pistons have been made altogether of metal, and in some cases, from working with less friction, these answer even better than the others.—2d. The next part to be mentioned is the *boiler* *B*, which is made of suitable size and strength.—3. The steam passes from the boiler along the pipe to *e*, and there, by any suitable *cock* or *valves*, worked by



the engine itself, is directed alternately to the upper and under part of the barrel ; and while it is entering to press on one side of the piston, the waste steam is allowed to escape from the other side, either to the atmosphere, for high-pressure-engines, or into—4th, the *condenser* at *c*, for those of low pressure ; the condenser being always kept at a low temperature by cold water running into it and pumped out again by the piston *k*.—5th. *The supply of steam* from the boiler to the cylinder is regulated by a *valve* placed somewhere in the pipe *b e*, and made obedient to what is called—6th, the *governor*, a contrivance not represented here, but already described at page 73, to illustrate centrifugal force. We may recall it be saying, that it consists of two balls hanging by jointed rods like the legs of a tongs, from opposite sides of an upright spindle, which is made to revolve by connexion with some turning part of the machinery :—when the spindle turns at all faster than with the desired speed, the balls fly more apart, and are made to affect the steam valve so as to narrow the passage ; and on the contrary, when it turns more slowly than is desired, they collapse, and by so doing open the valve wider.—7th. *The supply of water* to the boiler is regulated by a *float* on the surface of the water in the boiler ; which float, on descending to a certain point, by reason of the consumption of water, opens a valve to admit more.—8th. There is a *safety valve* in the boiler, *viz.* a well-fitted flap or stopper, held against an opening by a weight, but loaded so as to open before danger can arise from the overheating of

the water.—9th. The *rapidity of the combustion*, or force of the fire, is exactly regulated by the state of the boiler and the wants of the machine, thus:—there is a large open tube (not represented here) rising from near the bottom of the boiler, through its top to a height of several feet, and when the water in the boiler is too hot, and the steam therefore too strong, part of the water is pressed up into this tube, and by the agency of a float which rests on its surface, it shuts the chimney-valve, or *damper*: the draught is then diminished and the fuel saved, until a brisker fire is again required.—10th. In this figure *a i g* marks the place of the *great beam*, turning on an axis at *i*, and transmitting the force of the piston to the remote machinery. When the object is to raise water, the pump-rods are simply connected with the end *g* of the beam, but when any rotatory motion is wanted, the end *g* is made to turn—11th. a *crank l n* by the rod *g l*; and uniformity of motion is obtained by the influence of—12th. the great *fly wheel m*, fixed to the axis of the crank.

The smallest and simplest steam-engine, and therefore the cheapest, is that called the *high-pressure engine*. In it steam is used of great density, and consequently of great force, as of 50lbs. or more to the inch; and while the fresh steam is admitted to press on one side of the piston, the steam which has already worked is allowed to escape, or is driven out to the air, from the other side. The atmospheric resistance to the issue of the steam diminishes the working force of the piston just 15 lbs. per inch. The simplicity of

this form of engine recommends it, but the danger of a large boiler of over-heated water, always, like inflamed gunpowder, seeking to escape, has by numberless fatal accidents been proved to be so great, that the use of such an engine is limited to certain situations. Notwithstanding all the ingenious securities recently contrived against the danger, and which suffice for small engines, such as are required for steam-carriages, the high-pressure engine is not employed in a single English passage-vessel.

In the low-pressure engine, the steam is used generally of force not exceeding 20lbs. on the inch, which force is only 5lbs. more than the atmospheric pressure, and is insufficient to burst a common boiler or to do serious mischief: but as the interior of the low-pressure engine is kept in a state of vacuum, except where the steam is acting, the whole pressure of 20lbs. is made available, and the engine has the same power, if of equal size, as a high-pressure engine working with steam of 35 lbs. on the inch. The required vacuum is preserved by means of a separate vessel or box, represented at *c*, called the condenser, into which cold water is constantly running to condense the steam, and is afterwards pumped out with the condensed steam, and with any little air that may have entered: the pump is represented at *k* in the figure. Steam on coming into contact with a cold body is condensed almost with the rapidity of an explosion; and therefore the instant that opened valves make a communication between the cold condenser and any part of the engine containing

steam, this rushes to the condenser, and becomes water, leaving a vacuum behind. The great merit of Mr. Watt was in the contrivance of this separate condenser, for, until his time, cold water had always been thrown directly into the working cylinder, cooling it so much, that twice or thrice its fill of steam was destroyed at each stroke to warm it again before it could work. This single change saved three-fourths of the quantity of fuel formerly expended.

Before Watt's day, the only steam-engine in use was a rude *single-stroke engine*, as it was called, in which steam, admitted under the piston, allowed the weight of the pump-rods at the far end of the beam to lift the piston, and the steam being then condensed so as to leave a vacuum in the cylinder, the pressure of the atmosphere pushed the piston down to do its work: on this last account the engine was also called an *atmospheric engine*. It was used almost solely for pumping water; but it wasted so much fuel, from causes of which the chief is mentioned in the last paragraph, that the expense was not much less than that of employing horses.

In the atmospheric engine, the steam which lifted the piston against the atmospheric pressure, required to be at least as strong as that pressure, to the very end of the stroke. Another of Watt's great improvements was, his excluding altogether the air from his machine, by doing which he not only avoided the cooling effect of the air, but was at liberty to shut off the steam, as it is expressed, or to stop the supply for each stroke, before the cylinder was full, and then to make the further



expansion of the quantity admitted impel the piston to the end of the stroke. This principle of causing the mere expansion of steam to do work was afterwards carried to a great extent by Messrs. Hornblower, Woolfe, and others, who constructed engines with two barrels, in the first and smaller of which, the steam was made to act in its dense or strong state, as it issued from the boiler, and when it had finished a stroke there, instead of being at once sent useless to the condenser, it was admitted to a larger piston, which it moved by its continued expansion alone :—the same steam thus doing double work or more. All the advantages of the two cylinders, however, are obtainable from the single cylinder with its condenser, as now used in most of the Cornish mines. Steam of about 60lbs. pressure on the inch is admitted to the cylinder, until the piston is driven nearly one-third of its way, and the valve being then shut, the same steam is left to finish the stroke by its expansion. The pressure of the expanding steam gradually diminishes, it is true, in proportion as the volume increases ; but in pumping water there is a great saving of time, from having the power more intense at the beginning of the stroke, when the vast mass of water and machinery has first to be put into motion. Steam while doubling its volume by mere expansion, will do about *two-thirds* as much work as while originally rising from the boiler, and by every subsequent doubling it might do as much as by the first : the increasing size of the cylinder, however, and increased friction, confine this mode of using it to narrow limits.

It might be supposed that high-pressure engines without condensers would be comparatively wasteful, because in them the steam which has acted must be driven out of the cylinder against the powerful resistance of the atmosphere, while in the low-pressure engine it has instant access to the condenser, and leaves effective the whole pressure of the fresh steam on the opposite side of the piston. But as in the low-pressure engine, nearly half the power of the steam is expended in overcoming the friction and other impediments of the numerous parts; while in that of high-pressure, the parts are so much fewer, and the piston is so much smaller in proportion to the force acting upon it, that the loss from friction is often less than a fourth or even a sixth of the steam-power,—although the resistance of the air is to be overcome by the high-pressure engine, still there is often a saving on the whole. The saving becomes very considerable if the steam be allowed to act by its expansion also, as described in the last paragraph.

From misapprehension of the law of increase of force by increase of heat in water, explained by the table at page 389, some exceedingly false conclusions have been drawn, and acted upon at great expense (as lately by Mr. Perkins), in attempts to make engines to work with an excessively high pressure. Besides making the error now alluded to and others, Mr. Perkins overlooked the fact, that we possess no material for cylinders and pistons, strong enough to bear the contemplated pressure and friction even for a moderate time. Perhaps more striking examples could not be

adduced of the absurdities into which even highly ingenious men may fall, when not sufficiently acquainted with the general truths of nature on which the arts which occupy them are founded, than in the history of supposed inventions and improvements connected with the steam-engine.

The fertile genius of James Watt did not stop at the accomplishment of the two or three important particulars described above, but throughout the whole detail of the component parts, and of the various applications of the engine, he contrived miracles of simplicity and usefulness. We should exceed the prescribed bounds of this work by entering more minutely into the subject; but we may remark that, in the present perfect state of the engine, it appears a thing almost endowed with intelligence. It regulates with perfect accuracy and uniformity the *number of its strokes* in a given time, *counting* or *recording* them moreover, to tell how much work it has done, as a clock records the beats of its pendulum;—it regulates the *quantity of steam* admitted to work;—the *briskness of the fire*;—the *supply of water* to the boiler;—the *supply of coals* to the fire;—it *opens and shuts its valves* with absolute precision as to time and manner;—it *oils its joints*;—it *takes out any air* which may accidentally enter into parts which should be vacuum;—and when any thing goes wrong which it cannot of itself rectify, it *warns its attendants* by ringing a bell:—yet with all these talents and qualities, and even when exerting the force of hundreds of horses, it is obedient to the hand of a child;—its aliment is coal, wood, charcoal, or

other combustible ;—it consumes none while idle ;—it never tires, and wants no sleep ;—it is not subject to malady when originally well made ; and only refuses to work when worn out with age ;—it is equally active in all climates, and will do work of any kind ;—it is a water-pumper, a miner, a sailor, a cotton-spinner, a weaver, a blacksmith, a miller, &c. &c. : and a small engine in the character of a *steam poney*, may be seen dragging after it on a rail-road a hundred tons of merchandize, or a regiment of soldiers, with thrice the speed of our fleetest horse coaches. It is the king of machines, and a permanent realization of the *Genii* of Eastern fable, submitting supernatural powers to the command of man.

We need not wonder that the inventor of an engine having such qualities, should be deemed deserving of the highest honours from his fellow-men. In November 1825 a public meeting was called, to vote a monument to WATT, then not long deceased ; and the most distinguished men of the empire, of all parties, philosophers, and statesmen, met to vie with each other in speaking his praise. Perhaps a series of such eloquent discourses have rarely been pronounced at one time ; but perhaps in the progress of the arts of civilization there can rarely be offered such motive and occasion. The common voice of that assembly scarcely exaggerated, when attributing to WATT's genius and perseverance that increase of our national commerce and riches, which had enabled free Britain, single-handed, at an extraordinary crisis of human affairs, to contend with Europe



combined against her, and at last to triumph, so as to secure her own happy destinies, and probably much to influence those of the human race.

As science and the twin sister art are making constant advances, who shall say that even the steam-engine, perfect as we have described it, forms the limit to human discovery of mighty yet obedient force? It is true that the nature of steam, and the laws of its formation and action, are now so well understood, that the intelligent engineer no more hopes for great improvement in steam-engines, than he hopes for it in the mode of using a waterfall to turn a mill; but still there are kindred regions of nature left almost unexplored. We shall have occasion to make a remark on this subject in our chapter on the nature of *heat*.

*The explosion of gunpowder and of all fulminating mixtures* bears so strong an analogy to the phenomenon of the formation of steam, that the mind may advantageously contemplate the subject in this place.

The ingredients of which gunpowder is formed are chiefly substances which, when separate, exist, at any common temperature, in the form of air; and the combustion sets them loose, with a production of intense heat, causing an increase of volume which is instantaneous, and almost irresistible. By experiment and mathematical deduction, it appears that the exploding particles begin to separate from each other with a velocity as if ten thousand volumes of air had been condensed into one: and this explains the corresponding

force and swiftness with which a bullet is propelled.

All the fulminating metals are chiefly combinations of the like substances with the metals ; and the ingredients are held together by so slight a tie, that a little friction or elevation of temperature disunites them so as to produce the explosion.

The escape of condensed air from the chamber of an air-gun, is a species of explosion ; but is very gentle compared with the shock of discharged gunpowder.

It has lately been shewn that a gun-barrel may be connected with a high-pressure steam-boiler, in the same manner as with a chamber of condensed air ; and as the steam may be supplied as long as water remains in the boiler, if bullets be allowed to fall into the barrel fast enough, a hundred or more may be thrown out every minute, with the same force and precision as if each issued from a common fire-arm. The rapid succession resembles the issue of water from a jet pipe ; and if such an engine were used in a field of battle, its barrel of death, made to point gradually along a line of men, would mow them down like corn-stalks before the scythe—none could escape. The horrible idea and proposal have been excused by saying, that to prove the possibility of such carnage must have the effect of putting an end to war altogether.

The invention of gunpowder, with the consequent change of military tactics, because it gave to a handful of men possessing it the mastery over thousands who had it not, was hailed by the philosophers of the day as a certain security against

the relapse of civilized mankind into such a state of barbarism as followed the irruption into Europe of the Goths and Vandals:—none but well instructed and disciplined armies could then enter a European kingdom. This consideration, however, has lost its interest, since the invention of printing, and other changes in society, have afforded still better and more humane securities.

Besides the interesting instances above cited of the pressure of the atmosphere determining whether certain substances shall or shall not have the form of air, there are others that deserve mention, where the effect is modified by the mutual attraction of substances.

The pressure of the atmosphere at the surface of the earth keeps a certain quantity of air in combination with water, so as to form part of the liquid mass. This air re-appears at once on taking off the pressure. If we place a glass of water under the receiver of an air-pump and then exhaust this, the water is soon crowded with bubbles of air, seen adhering to the glass all around, or rising through the water. This admixture of air in water is necessary to the life of fishes. It is driven off by boiling, and hence the vapid taste of water that has recently been boiled.

In the making of beer, wine, and other fermented liquors, there is formed, during the fermentation, a large quantity of the substance called carbonic acid. Much of it flies off in its usual form of gas, but, because of the pressure of the atmosphere, much still remains in union with the

liquid. On removing this pressure suddenly, the liquid appears almost to boil, as when a glass of warm beer is placed in the air-pump vacuum.

A degree of pressure still greater than that of the atmosphere, keeps a proportionally larger quantity of this carbonic acid in liquid combination; as in bottled porter or sparkling champaigne before the cork is drawn; but as soon as the compression maintained by the cork is removed, the gas escapes, causing the thin champaigne to sparkle, and the more viscid beer, which retains the little bubbles as they rise, to be covered with froth. After the sparkling or frothing have ceased under the atmospheric pressure, the phenomenon may be renewed by placing the glass in the air-pump receiver.

Carbonic acid so readily becomes liquid when its attraction for water assists the compression, that enough of it may be united with water to make a pint become a pint and a half. The soda water, or aerated water, now so generally used as drink in warm weather, is water with several times its bulk of carbonic acid forced into it by pressure; and a part of this is seen escaping always at the instant of the confining cork being drawn.

Carbonic acid forms nearly half of the substance of marble or lime-stone. When an acid with stronger attraction, as vinegar or sulphuric acid, is poured upon marble, it dispossesses the carbonic acid, and unites itself with the pure lime. The carbonic acid in rising, constitutes the effervescence which then appears. Carbonic acid, for the manufacture of the common soda water and other aerated drinks, is obtained in this way.



Many mineral waters contain carbonic acid, which remains in tranquil combination while the water is bearing a certain pressure under ground, but which in part escapes as soon as the water issues to the air and only the atmospheric pressure remains: such waters are called sparkling waters.

The reason that champagne and the aerated waters are so cool when first decanted is, that the carbonic acid, in assuming its gaseous form, absorbs, as latent heat, a large proportion of the heat which was previously existing in the liquid.

The atmospheric pressure, by making the density of the air in any place dependent upon the height of the place above the level of the sea, causes corresponding differences of temperature.

The explanation of this is simple. If a gallon of air at the surface of the earth contain a certain quantity of heat, this must be diffused equally through the space of the gallon; but if the air be then compressed into one-tenth of the bulk, there will be ten times as much heat in that tenth as there was before; the increase affecting the thermometer to an extent modified by circumstances explained in a future part of this work. In like manner, if by taking off pressure the gallon be made to dilate to ten gallons, the heat will be in the same degree diffused, and any one part will be colder than before. It is known that air may be so much compressed under the piston of a syringe, that the heat in it similarly concentrated, becomes intense enough to inflame tinder attached to the bottom of the piston:—this means,

under the name of the *match-syringe*, being in common use for obtaining an instantaneous light.

Now, for the reason here explained, the air near the surface of the earth, forming the bottom of the atmosphere, because condensed by the weight of the air above it, is much warmer than if it were suddenly carried higher up, to where, from the pressure being less, it would be more expanded or thin. In many cases the height of mountains may be estimated by the difference of temperature observed at the bottom and at the top. While a thermometer stands at  $60^{\circ}$  at the bottom of St. Paul's Cathedral in London, another marks only  $58^{\circ}$  at the top of the dome; and in the lofty ascent of a balloon, the thermometer soon falls to the freezing point and below it, the cold to the aeronaut becoming almost insupportable.

In every part of the earth, at a certain elevation in the atmosphere, different according to the latitude or proximity to the equator, the thermometer never rises above the freezing point,—and this limit in the atmosphere is called the line or level of perpetual congelation. In Norway it is at five thousand feet above the level of the sea; in Switzerland at six thousand five hundred; in Spain and Italy at seven thousand; farther south, at Teneriffe, at nine thousand; directly under the sun, as in central Africa, and among the Andes in America, it is about fourteen thousand. We see therefore why the snow-capt mountains are not the tenants only of high northern and southern latitudes. It is this effect of elevation which renders many of the tropical regions of the earth not

only tolerable abodes for man, but as suitable as any others, contrary to the opinion of the ancient philosophers of Europe, who accounted them, by reason of the great heat, an everlasting barrier, as regarded man, between the northern and southern hemispheres. Much of the tropical land of America is so raised, that it rivals, as to agreeable temperature, even a European climate ; while the lightness and purity of the air, and the brightness of the sun, add delightfully to its charms. The vast expanse of table-land forming the empire of Mexico is of this kind, enjoying the immediate proximity of the sun, and yet, by its elevation of seven thousand feet above the level of the ocean, possessing the most healthful freshness. The land in many parts has the fertility of a cultivated garden, and can produce naturally most of the riches which vegetation offers over the diversified face of the globe. The plains of Columbia, in South America, and indeed all along the ridge of the Andes, are similarly circumstanced. The contrast is very striking, after sailing a thousand miles up the level river Magdalena, in a heat scarcely equalled on the plains of India, at once to climb to the table-land above, where *Santa Fé de Bogota*, the capital of the republic, is seen smiling over interminable plains, that bear the livery of the fairest fields of Europe!

Persons not understanding the law which we are now illustrating, will express surprise that wind or air blowing down upon them from a snow-clad mountain, should still be warm and temperate. The truth is, that there is just as much heat com-

bined with an ounce of the air on the mountain top as in the valley : but above, the heat is diffused through a space perhaps twice as great as when below, and therefore is less sensible. It may be the same air which sweeps along as a warm gale on a plain at the foot of a mountain,—which then rises and freezes water on the summit—and which in an hour after, or less, is playing among the flowers of another valley, as warm and genial as before.

As the temperature in different parts of the atmosphere depends thus upon the rarity of the air, and therefore upon the height, the vegetable productions of each distinct region or elevation are of a distinct character ; and many other peculiarities of place and climate acknowledge the same cause.

Because the atmospheric pressure determines the temperature of the air in different situations, as now explained, it has also a corresponding influence upon the state of aerial humidity, which is modified by the temperature.

It was explained at page 388, that water and other liquids under a vacuum, rise in the form of air or vapour with force, and in quantity having a strict relation to the temperature—heat being in fact the cause of their rising ; and the table at page 389 exhibits the force, and therefore the density of watery vapour corresponding to some certain temperatures. Now it is a remarkable circumstance, that vapour in the same quantity and of equal tension rises from any liquid, whether placed under the pressure of air, or under a vacuum ;



only through a space containing air it diffuses itself more slowly than if the air were not present. As regards the former case, it was for a long time supposed that the air dissolved the liquid as a liquid dissolves a salt: but it now appears that there is merely a mechanical mixture of the two. If the vapour, while rising from a liquid, has not a tension or elastic force equal to the pressure of the atmosphere, the process is tranquil, and is called *evaporation*, and it goes on only as the vapour can diffuse itself among the particles of the air, and therefore slowly in air perfectly quiescent, but quicker as the air is moving more, or as the density of the air is less. But when the vapour, owing to greater heat, is strong enough to overcome the atmospheric pressure of fifteen pounds per inch, and the weight of a certain quantity of liquid over it, the phenomenon of boiling arises as already described.

For the reason now explained, the air of our atmosphere contains diffused through it a large quantity of invisible aeriform water; and if there were no intestine motions, and no changes of temperature in the atmosphere, the quantity of water would soon everywhere reach a *maximum*, or would be the greatest that the temperature of the place could support: instead of this, however, from a variety of causes to be explained below, the air is moving about constantly as winds, and the local temperatures are ever fluctuating, and when the temperature is lowered, in situations where a maximum of watery vapour is present, part of this is instantly reduced to the state of water again, and

appears, according to circumstances, in the form of *mist*, *rain*, *snow*, or *hail*; while to supply material for these phenomena, evaporation is going on wherever, over water, there is not a *maximum* of vapour in the air. These opposing operations of evaporation and condensation keep up that constant circulation of moisture which is the life of nature.

When a given quantity of water assumes the aeriform state, it contains the same quantity of latent heat in all cases, whether rising, for instance, from a boiling cauldron, or from the surface of a lake. Hence we see why evaporation is so cooling a process to any liquid or moistened solid from which it is arising: and as we have already shewn that a rapid passing of dry air, or the substance being placed in a vacuum, quickens evaporation, we now see why both of these conditions accelerate the cooling. Wet linen placed in a strong wind, which does not contain a maximum of moisture, becomes dry almost immediately; a bottle of wine covered with a wet cloth and suspended in a current of air, as is practised in warm climates to prepare wine for the table, is quickly cooled; mats hung around the walls of houses in India, and frequently wetted through the day, preserve a delightful freshness in the apartments. Sprinkling water or vinegar over a hot sick-room cools and refreshes it; and watering the streets of a city moderates in them the intensity of summer heat. In warm climates water is cooled for drinking by being put into vessels so porous that the external surface is always moist, the vessels being

then suspended in a current of air, or during a calm being made to vibrate in the manner of a pendulum. Again, the rapidity of evaporation from water under the exhausted receiver of an air-pump, and particularly when some other substance which powerfully absorbs watery vapour is included in the receiver, is so rapid, and carries off the heat so quickly, that the mass of water freezes before much of it has been carried away. This process is used for making ice in India.

It is partly because air saturated with moisture, that is to say, having as much water diffused in it as can be supported in the invisible or aeriform state of the existing temperature,—lets fall a part on any reduction of the temperature, that air which, as a portion of the atmosphere, has been heated by the sun during the day, and has received much moisture, lets it fall again during the night, and exhibits the night fogs of certain seasons, which float upon the surface of the earth, until again acted upon by the beams of the next morning's sun. Fog when farther condensed, by groups of the minute particles uniting, forms rain; and rain when cooled becomes snow or hail.

The quantity of dew which falls at night is influenced by the quantity of moisture taken up by the atmosphere during the heat of the day; and the immediate cause of the dew is, as was ingeniously proved by Dr. Wells some years ago, that the temperature of the objects on which it settles has become lower during the night than that of the air around, and than is required to maintain in the invisible state, the moisture in the surrounding

atmosphere. There is a tendency in heat to diffuse itself uniformly among bodies, by a constant radiation from one to another, rapid in proportion to the differences of temperature, and which if continued would reduce all to the same degree. The earth, therefore, during the day, receives radiated heat from the sun, and becomes comparatively hot, and during the night it gives out heat again by radiation towards the sky, from which there is little or no return. When there are clouds in the atmosphere at night, they receive the heat darted upwards from the bodies on the earth's surface, and they radiate heat back, becoming thus, as it were, a clothing to maintain the warmth of the earth beneath them,—and on cloudy nights there is no dew,—but with a clear sky, the heat radiated upwards darts into boundless space, and is lost altogether to the objects which emitted it. These objects, therefore, which during the day had the same, or even a higher temperature than the atmosphere around, now become colder, and the aeriform water which comes in contact with them is condensed, and forms what we call dew. This beautiful provision of nature supplies the necessary moisture to vegetables during seasons when rain is deficient. Dew on very cold objects freezes as it settles, and is then called *hoar frost*. A phenomenon which may be classed with dew, is the perspiration, as it is vulgarly called, of massive walls and furniture, occurring on the sudden setting in of warm weather, or on the occasion of a warm moist air of higher temperature than the walls being suddenly introduced, as when a crowd assem-



bles in a cold church :—the wall or other object then, from not having yet acquired the temperature of the surrounding air, condenses upon itself a copious deposition of the atmospheric moisture. For a similar reason a bottle of wine brought from a cold cellar or from an ice-pail, into a room with company, is soon covered with thick moisture or dew ; as are the glasses also into which the wine is poured. It is another phenomenon of the same kind when we see the moisture of warm breath condensed on any cold polished surface, as on a mirror's face, or on the glasses of a carriage shut up, or on the windows of a room in winter, when the surface is very cold, the moisture being frozen with the appearance of beautiful arborescence.

Many instruments have been contrived, with the name of *hygrometers*, for indicating the quantity of water in the atmosphere. A prepared human hair is the essential part of one of the best of those formerly used ; the lengthening or shortening of the hair, according to the quantity of moisture around it, being caused to move an index like that of a wheel-barometer, to mark the degrees. This, however, and other common hygrometers, are only philosophical toys ; but Mr. Daniel (see his excellent work, entitled *Meteorological Essays*) has lately given to the philosophical world a correct and simple instrument for the purpose, depending on the principle explained above, —that whenever the temperature of a body in the atmosphere is reduced below that at which the quantity of watery vapour in the air around it can be maintained in the aeriform or invisible state,

dew forms on the body. His apparatus consists of a bulb of glass, which can be cooled to any desired degree from being connected with another bulb enveloped in an evaporating liquid; and when moisture begins visibly to settle upon the first, its temperature is exhibited on a thermometer enclosed within it; and the proportion of water mixed with the air around is then, as indicated by the table, partially copied here, at page 389.

A great fall of the barometer marks a diminished pressure in the atmosphere around, with a consequent dilatation of the air and fall of temperature, as explained a few pages back; and if the air at such a time hold a maximum of moisture, a part of this must become visible as fog or rain. Thus a fall of the barometer, a fall of temperature, and a fall of rain, often occur as associated phenomena.

Illustrating this by experiment, we find, that on the extraction of air from the receiver of an air-pump, a cloud or mist generally appears in it with the first strokes of the piston:—the reason being that the still remaining air, because cooled by the rarefaction, absorbs heat from the vapour in combination with it, and renders the water visible. The mist is then removed by the subsequent action of the machine, or is re-dissolved when the usual quantity of air is re-admitted.

We understand from this why rain happens so much more frequently among mountains than on extended plains. When air saturated with moisture approaches a mountain ridge to rise over it, for every foot that it rises, it escapes from a degree of the pressure which it bore while lower down,

and in then dilating, it becomes colder, and lets fall part of its moisture. It is the rain copiously thus produced in mountainous regions which constitutes the chief supply of their many rivers, and which, with periodical changes of wind bringing more moisture, causes the extraordinary annual overflowing of such rivers as the Nile, the Ganges, &c.

Those who have visited the Cape of Good Hope, will recollect a striking phenomenon illustrative of our present subject, observed there when the wind blows from the south-east. Beyond the city, as viewed from the bay, there is a mountain of great elevation, called, from its extended flat summit, the Table Mountain. In general its rugged steeps are seen rising in a clear sky ; but when the south-east wind blows, the whole summit becomes enveloped in a cloud of singular density and beauty. The inhabitants call the phenomenon the spreading of the table-cloth. The cloud does not appear to be at rest on the hill, but to be constantly rolling onward ; yet, to the surprise of the beholder, it never descends, for the snowy wreaths seen falling over the precipice towards the town below, vanish completely before they reach it, while others are formed on the other side to replace them. The reason of the phenomenon is this. The air constituting the wind from the south-east having passed over the vast southern ocean, comes charged with as much invisible moisture as its temperature can sustain. In rising up the side of the mountain it is rising in the atmosphere, and is therefore gradually escaping from a part of the pressure

lately borne ; and on attaining the summit it has dilated so much, and has consequently become so much colder, that it lets go part of its moisture. This then appears as the cloud just described ; but it no sooner falls over the edge of the mountain, and again descends in the atmosphere to where it is pressed, and condensed, and heated as before, than it is re-dissolved and disappears :—the magnificent apparition dwelling only on the mountain top.

When the elevation to which moisture is suddenly carried is very great, the fall of temperature is proportional, and the separating water becomes snow instead of rain. This phenomenon is remarkably illustrated by a great *Hiero's* fountain, used in one of the mines of Hungary ; during the play of which, the air in one place is so compressed, that on being suddenly released, it expands and cools enough to cause the moisture driven out with it to appear, even in summer, as a shower of snow.

The foregoing reasoning explains why, along the sides of mountain ridges, clouds are generally seen floating at a certain height only, and therefore in horizontal strata. The water is separated from the air at a certain temperature, which is dependent on the height, and above that height the air is at the time too dry and rare to have clouds. Very lofty summits are always seen much above the clouds, and the admirer of nature who climbs towards them, may often contemplate the grand phenomena of the thunder-storm far beneath his feet. Teneriffe soars so sublimely, that the distant



sailor not unfrequently mistakes the line of clouds hanging around its sides for the white streak which elsewhere indicates the cliffs and waves of the sea-shore.

*Fluid support or floating, in air.* (Read the Analysis, page 320.)

When it was explained, under “Hydrostatics,” that any body immersed in a fluid has its downward tendency or weight resisted with exactly the force which supported the quantity of the fluid previously occupying the same space, and therefore that the body will sink or swim, according as it is heavier or lighter than its bulk of the fluid, the reasoning was as applicable to the case of a body immersed in an air or gas as in a liquid.

We hence see why a body weighed in air appears lighter, by the exact weight of its bulk of the air, than when weighed in an empty space or vacuum;—and why, for the same reason, the jocular question, whether a pound of lead or a pound of cork be the heavier, is not truly answered by saying that they are of equal weight; the cork being really the heavier, for when balanced in air, bulky cork is more supported than dense lead. A small weighing-beam having attached to its opposite ends pieces of cork and lead which equipoise in the air, if placed under the exhausted receiver of an air-pump, quickly exhibits the cork preponderating.

As any liquid lighter than water, such as oil or spirits, on being set at liberty under the surface of water, will rise, while any heavier liquid, such as

brine, syrup, or sulphuric acid, will sink; and in both cases with force proportioned to the difference of specific gravities:—so we find, that in common air, a mass of hydrogen, or hotter air, ascends, because specifically lighter; while oxygen, carbonic acid gas, or colder air, descends, because specifically heavier. This truth is well exemplified in

*The Balloon,*

which is a thin light bag of varnished silk, generally shaped like a globe or egg, and filled with a fluid lighter than common air. It is made sufficiently large that the difference between its weight when filled and that of an equal bulk of common air, may enable it to carry aloft the material of which it is constructed, with the aeronauts, and their apparatus. It is in principle like a bladder of oil immersed in water. A globe of thirty-five feet diameter has a capacity of nearly twenty-two thousand cubic feet. This quantity of common air weighs about *sixteen* hundred pounds, and the same quantity of hydrogen gas, of easily obtained purity, weighs only one-eighth as much, or *two* hundred pounds. Such a globe, therefore, being buoyed up, or supported in common air, with a force of sixteen hundred pounds, while if filled with hydrogen, it only weighs two hundred, will carry up into the sky fourteen hundred pounds of material and load.

The first balloon was exhibited by a man ignorant of what he was really effecting. Seeing the clouds float high in the atmosphere, he thought that if he

could make a cloud, and enclose it in a bag, it might rise and carry him with it. Then erroneously deeming smoke and a cloud the same, he made a fire of green wood, wool, &c., and placed a great bag over it with the mouth downwards to receive the smoke. He soon had the joy to see the bag full, and when set free, ascending; but he understood not that the cause was the hot and dilated air within, which, being lighter than the surrounding air, was buoyed up; while the visible part of the smoke, which chiefly engaged his attention, was really heavier than the air, and was an impediment to his wishes.

This modification, called the *hot air or fire balloon*, was afterwards better understood, and was used by aeronauts, until the more commodious and less dangerous modification, called the *inflammable air balloon*, or balloon of hydrogen gas, was substituted.

Since the modern introduction of gas lights, the *carburetted hydrogen* prepared for them is generally employed for filling balloons. It is considerably heavier than pure hydrogen, but is so much more readily obtained, that aeronauts like better to make a larger balloon to suit it, than a smaller one which obliges them to prepare the other.—A thin paper bag, filled with the hot air rising from a large lamp, is a miniature *hot air or fire balloon*; and a common soap bubble filled with hydrogen, is a little *inflammable air balloon*, which mounts with great rapidity.

There are perhaps few occasions on which a youth is more surprised and delighted than when

he first beholds a balloon sailing high in the bosom of the air, and bearing a human being to regions far beyond what the soaring eagle has ever reached: while to the intrepid aeronaut himself the scene of a world displayed beneath him is unquestionably the grandest, except that of the starry heavens, which mortal eye has ever compassed. To him even wide-spread London, the queen of the cities of the earth, and a little world within itself, when viewed from a great elevation in the sky, appears but as a dusky patch upon a map, with the far-famed Thames winding there as a silvery line, and the magnificent temples and palaces scattered around, appearing but as darker points rising out of the general mist of buildings, in which a million and a half of human beings reside.

The first aeronautic expeditions astonished the world, and endless reveries passed through men's minds of important uses to which the new discovery might be applied; but more mature reflection, and now frequent trials, have shewn that the balloon, while furnishing philosophers with the opportunity of making some observations in elevated regions of the atmosphere, is still interesting chiefly as a philosophical toy. The French, under the Directory in 1796, attempted to use it as a military station, from which the position and motions of an enemy might be descried: but the plan was eventually abandoned. It has since been thought of as a means by which travellers might obtain information, while penetrating into unknown countries, like the almost interminable plains of *Australasia*. Although aeronauts, while



aloft, have the power of making the balloon rise farther by throwing out part of the sand-ballast which they carry with them, or of making it descend by opening a valve at the top through which the hydrogen may escape, still they have no power of producing a lateral motion. The idea which yet strongly excites the minds of some projectors, that by wings or other means a balloon may be directed in the sky, nearly as a ship is directed on the sea, is not much more reasonable than to suppose that an insect, suspended to a huge block of wood, driven along at the rate of eight or ten miles an hour by a river torrent, should have power to stop or sail against the stream. A man in a balloon would generally have to resist or change a motion exceeding fifty miles in an hour.

A balloon which is only half full at the surface of the earth, becomes quite full when it has risen three miles and a half, because at that altitude, air from below doubles its volume on account of the diminished pressure. A balloon, therefore, if quite distended on first rising, must let air escape as it ascends, or it will burst: this is true also of the drum of the human ear under the same circumstances, and in a contrary way under the opposite circumstances of a person descending in a diving-bell.

The downy seeds of plants seen floating about upon the winds of autumn, are not lighter than air, but have so much bulk and surface in proportion to their weight, that the friction upon them of the

moving air is greater than their weight, and carries them along.

A sheet of paper, made in some degree to resemble a balloon, by its having a little weight, representing the hanging car, attached by threads from its angles, is often seen rising at a street corner, to the delight of the boy who watches it. Its rise depends upon eddy winds or currents which the corner produces.

*The ascent of flame and smoke*

in the atmosphere, affords other examples of a lighter fluid rising in a heavier ; for both these are merely hotter air rising in the midst of colder.

The phenomenon of flame is produced when a burning substance contains some ingredient capable, on being heated, of assuming the form of air or gas, which ingredient on ascending, burns or combines with the oxygen of the atmosphere, with intensity of action sufficient to produce a white heat. It is because charcoal and coke have nothing in them thus volatile, that they burn without flame, appearing like red-hot stones. The flame of a lamp or candle is merely the oil, wax, or tallow converted into gas, and allowed to burn as it is disengaged and rises. The same gas obtained by heating the oil, &c. in vessels which exclude the atmosphere, so as to prevent immediate combustion, and from which tubes lead to suitable receptacles, is the common oil-gas used for illumination.

Smoke consists of all the dust and visible particles which are separated from the fuel without

being burned, and are moreover light or minute enough to be carried aloft by the rising current of heated air; but all that is visible of smoke is really heavier than air, and soon falls again, as powdered chalk falls in water. In the receiver of an air pump, where a candle has been extinguished by exhausting the air, the stream of smoke that continues to pour from the wick after the exhaustion, is seen to fall on the pump-plate, because there is no air to support it.

*Chimnies* quicken the ascent of hot air by keeping a long column of it together. A column of two feet high rises or is pressed up with twice as much force as a column of one foot, and so in proportion for all other lengths; just as two or more corks strung together, and immersed in water, tend upwards with proportionally more force than a single cork; or as a long spear of light wood, allowed to ascend perpendicularly from a great depth in water, acquires a velocity which makes it dart above the surface, while a short piece under the same circumstances rises very slowly. In a chimney where one foot in height of the column of hot air is one ounce lighter than the same bulk of the external cold air, if the chimney be one hundred feet high, the air or smoke in it is propelled upwards with a force of one hundred ounces. In all cases, therefore, the *draught*, as it is called, of a chimney, is proportioned to its length. The following facts are consequences of this truth.

In low cottages, and in the upper floors of houses, the annoyance of smoky rooms is much more frequent than where chimneys are longer.

If there are two fires in the same room, or in any rooms open to each other, which have chimnies of different lengths, and of which the doors and windows are very close, so that air to supply the draughts cannot enter by them, the taller chimney will overpower the shorter, and cause it to smoke into the room ; just as the long leg of a syphon overcomes the short one, or as a long log of wood, held down in water by a cord passing from it round a pulley at the bottom to a shorter log also floating, will rise, and pull down the shorter log.

A long chimney, for the reasons above explained, causes a current of air to pass through the fire very rapidly, and it has the advantage also of acting more uniformly than any bellows or blowing machine. On these accounts, for fires of steam-engines, and many others, it is the means of blowing generally preferred. The importance of length in a chimney explains the remarkable appearance of some mining districts and modern English towns, where steam-engines abound.

When we heap dying embers together, so that the hot air rising among them may become a mass or column of considerable altitude, this column has the effect of blowing them gently, and helps to light them up again. A piece of burning paper thrown upon the top of a half-extinguished fire, often makes it blaze afresh, by causing a more rapid current of air to pass through it from below.

The action or draught of a chimney, influenced, as we have seen, by its length, depends also on



the degree in which the air in it is heated, because this determines the dilatation, or comparative lightness, which makes the air ascend.

In what are called *open fire-places*, such as those in the sitting-rooms of Britain, a large quantity of air directly from the apartment enters the chimney above the fire, and mixes with the hot air from the fire itself. This mixture ascends more slowly than if hot air alone entered, and in a proportion dependent on the degree of mixture. The effect of excluding a part of this colder air, is seen when a board or plate of metal is suspended across the opening of the chimney, so as to narrow the entrance:—almost instantly a quicker action is produced, and the fire begins to roar as if blown by a bellows. This means is often used to blow the fire instead of bellows, or to cure a smoky chimney, by increasing the draught. What is called a *register stove* is a kindred contrivance. It has a flap placed in the throat of the chimney, which serves to widen or contract the passage at pleasure. Because the flap is generally opened only enough to allow that air to pass which rises directly from the fire, the chimney receives only very hot air, and therefore acts well. The register stove often cures smoky chimneys: and by preventing the too ready escape of the moderately warmed air of the room, of which so much is wasted by a common fire-place, it also saves fuel. In what are called *close fire-places*, as those of steam-engines, or brewers' coppers, when the furnace door is shut, no air can enter the chimney

but directly through the fire : hence the action of such chimnies is very powerful.

In a room with two fires, or in drawing-rooms communicating with each other, although the chimnies be of equal length, that one over the best fire will act the most strongly ; and if the doors and windows of the apartment be so close as to prevent a sufficiency of air from entering by them to supply both fires, cold air will enter by that chimney which has the weakest fire, and the smoke from it will spread into the room. How often is an assembling dinner party annoyed by the smoke of a second drawing-room fire just lighted before their arrival, and which had therefore to contend with the antagonist fire, already in powerful action all the day. While only one fire was lighted, the cold chimney was admitting the air to feed it, just as an open pane in the window would have done. A room may be so close, that no air can find entrance, and in such a case the smoke of its fire must all spread into the room.

When all the windows and doors of a house fit so closely as not to admit air for the acting chimnies, the supply comes down the chimnies that are not in use. Inattention to this fact causes many a good chimney to incur the imputation of being smoky, because on the attempt being made to light a fire at it, the smoke at first is always thrown back. The truth is, that at the time when the servant begins to light the fire, there is a downward current in the chimney, repelling, of course, any heated air and smoke that approaches it, and spreading them over the whole house ; but were the room-

door to be shut for a few minutes, so as to cut off communication with the other *drawing* chimnies in the house, while at the same time the window were opened, the chimney would act at once ; and when sufficiently heated, would continue to act in spite of the others, and as well as they.

There are some cases of smoky rooms not to be so easily corrected as what we have now mentioned. When a low house adjoins a lofty house, the wind blowing towards the latter, is obstructed and becomes a gathering or condensation of air against the wall ; and if the top of a low chimney be there, the compressed air enters it, and pours downwards. The same happens occasionally from the proximity of trees or rocks. In such cases, to avoid the influence, the chimnies of the low house are often made very lofty. Again, whenever from the nature of buildings, eddies of wind occur, or unequal pressures, as at street corners, &c. the chimnies around do not act regularly. It is proverbial, that corner houses, or those at the ends of a row, are smoky houses ; and we see the uniformity of architecture in a street often destroyed by the necessity of lengthening the chimnies of the houses at the extremities.

When smoke is found descending into a room where there is no fire, the empty chimney is serving as an inlet for air to the house, while the smoke of a neighbouring chimney is passing closely over the top of it.

In summer, when fires are not in use, there is often a strong smell of soot perceived in the apartments during the whole of the day, but which

ceases at night. The reason is, that during the day the chimney is colder than the external air, and by condensing the air which enters it, causes a downwards current through the soot. During the night, again, when the external air becomes colder owing to the absence of the sun, the chimney, by retaining the heat absorbed during the day, is hot enough to warm the air in it, and to cause an upward current. These currents, in chimnies left open during the days and nights of summer, are almost as regular as the land and sea breezes of tropical countries.

All these remarks prove how important it is to be able to conceive clearly of the motions going on, according to the simple laws of matter, in the invisible air around us. Were such subjects better and more generally understood, many prevalent errors in the arts of life, influencing much the comforts and health of the community, would soon be corrected.

If we are filled with admiration on discovering how perfectly the simple law of a lighter fluid rising in a heavier, provides a constantly renewed supply of fresh air to our fires, which supply we should else have to furnish by the unremitted action of some expensive blowing apparatus ; still more must we admire that the operation of this law should effect the more important purpose of furnishing the ever renewed supply of the same vital fluid to breathing creatures. The air which a man has once respired becomes poison to him ; but because the temperature of his body is generally higher than that of the atmosphere around him, as



soon as he has discharged any air from the lungs, it ascends completely away from him into the great purifying laboratory of the atmosphere, and new air takes its place. No art or labour of his, as by the use of fans or punkas, could have done half so well what this simple law unceasingly and invisibly accomplishes, and accomplishes without effort or even attention on his part, and in his sleeping as in his waking hours. Truly in this, may he be said to be watched over by a kind providence.

*The warming and ventilating of houses*

is an important art, founded chiefly on the foregoing considerations, and at present too little understood, not only by the public at large, but even by medical practitioners, whose management of disease, though judicious in other respects, is often rendered vain by error or omission in this.

Excellent fuel is so cheap in Britain, owing to the profusion with which beds of rich coal are scattered in it, that a careless domestic expenditure has arisen; which, however, instead of securing the comfort and health that might be expected, has led to plans of warming which often prove destructive of both. The mischief lies chiefly in the unsteadiness or fluctuations of our domestic temperature; for in still colder countries, and where fuel is more expensive, as in the north of continental Europe, the necessity for economy has led to contrivances which give steady temperature and impunity.

In cold countries, to retain and preserve the heat once obtained, the houses are made with thick

walls, double windows, and nice fittings; and moreover with close stoves or fire-places, which draw their supply of air, not from the apartments where they are placed, wasting the temperate air of these, but directly from without. Thus fuel is saved to a great extent, and a uniformity of temperature is produced, both as regards the different parts of the room, so that the occupiers may sit with comfort where they please, and as regards the different times of the day, for the stove being once heated in the morning, often suffices to maintain a steady warmth until night. The temperature can be carried to any required degree, and sufficient ventilation is easily effected.

In England, again, the apartments, with their open chimnies, may be compared to great air-funnels, constantly pouring out their warm contents through a large opening, and constantly requiring to be replenished. They thus waste fuel exceedingly, because the chimney being large enough to allow a whole room-full of air to pass away in two or three minutes, the air of the room has to be warmed, not once in the course of the day, but very many times. The temperature in them is made to fluctuate by the slightest causes, as the opening a door, the omitting to stir the fire, &c. The heat is very unequal in different parts of the room, rendering it necessary in general for the company to sit near the fire; where they must often submit to be almost scorched on one side, while they are chilled on the other. There is generally a warm stratum of air above the level of the chimney-piece, surrounding, there-

fore, the upper part of the bodies of persons in the room, while a cold stratum below envelopes the sensitive feet and legs. As a very rapid current is constantly ascending in the chimney, a corresponding supply must be entering somewhere; and it can only enter by the crevices and defects in the doors, windows, floors, &c.:—now there is nothing more dangerous to health than to sit near such inlets, as is proved by the rheumatisms, stiff necks, and catarrhs, not to mention more serious diseases, which so frequently follow the exposure. There is an old Spanish proverb, thus translated,

“ If cold wind reach you through a hole,  
Go make your will, and mind your soul,”—

which is scarcely an exaggeration.

Consumption is the disease which carries off a fifth or more of the persons born in Britain; owing in part, no doubt, to the changeableness of the external climate, but much more to the faulty modes of warming and ventilating the houses. To judge of the influence of temperature in producing this disease, we may consider,—that miners who live under ground, and are always, therefore, in the same temperature, are strangers to it, while their brothers and relatives, exposed to the vicissitudes above, fall victims,—that butchers and others, who live almost constantly in the open air, so as to be hardened by the exposure, enjoy nearly equal immunity,—that consumption is scarcely known in Russia, where *close* stoves and houses preserve a uniform temperature within doors, while

fit clothing gives safety on going out,—and that in all countries and situations, whether tropical, temperate, or polar, the frequency of the disease bears relation to the degree and manner of change. We may here remark also, that it is not consumption alone which springs from changes of temperature, but a great proportion of acute diseases, and particularly of the common winter diseases of England. There are few cases of these in which the invalid has not to remark, that if he had avoided cold or wet on some certain occasion, he might yet have been well.

While temperature is thus so frequently an original cause of disease, it is also a circumstance of the very highest importance in the treatment,—as is proved by every fact bearing upon the question. We may, therefore, at first wonder that it should be so negligently and unskilfully controlled as we often see it; disease and death being thence allowed to lurk, as it were, undisturbed in the sanctuaries of our homes: but when we reflect on the subtile and invisible nature of air and heat, and that the science which detects their agencies has been hitherto so little an object of general study, and is indeed of modern discovery, the fact is accounted for.

In England, the open fire-place is so generally in use for common dwellings, and the cheerful blaze is accounted so essential to the comforts of the winter days and long evenings, that it would be difficult to persuade persons to abandon it: let us hope then, that when the subjects which we are now discussing come to be better and more ge-



nerally understood, the open fire, with close flooring, better or double windows, doors that fit well, register stoves, and good general management, may be rendered almost as efficient for warming, and as safe to health, as any other contrivance.

The following considerations present themselves in this place.—Small rooms in winter are more dangerous to health than large ones, because the cold air, entering towards the fire by the doors or windows, reaches the persons in the room before it can be tempered by mixing with the warmer air already around them.—Stoves in halls and staircases are useful, because they warm the air before it enters the rooms; and they prevent the hurtful chills often felt on passing through a cold staircase from one warm room to another.—It is important to admit no more cold air into the house than is just required for the fires and for ventilation; hence there is a great error in the common practice of leaving all the chimnies that are not in use quite open,—each admitting air as much as a hole in the wall, or an open pane in a window would do.—Perhaps the best mode of admitting air to feed the fires is through tubes, leading directly from the outer air to the fire-place, and provided with what are called throttle-valves, for the regulation of the quantity: the fresh air admitted by them being made to spread in the room either at once, or after having been warmed during its passage inwards, by coming near the fire.—In a very close apartment, ventilation must be expressly provided for by an opening near the ceiling, through which the impure air, rising from the respiration of the

company, may pass away. With an open fire, the purpose is effected, although less perfectly, by the frequent change of the whole air of the room which that construction occasions.

With a view to have, in rooms intended for invalids, the most perfect security against cold blasts and fluctuation of temperature, and still to retain the so much valued appearance of the open fire, a glazed frame or window may be placed at the entrance to the chimney or stove, so as completely to prevent the passage of air from the room to the fire. The room will then be warmed by the fire through the glass, nearly as a green-house is warmed by the rays of the sun. It is true, that the heat of combustion does not pass through glass so readily as the heat of the sun; but the difference for the case supposed is not important. The glass of such a window must, of course, be divided into small panes, and supported by a metallic frame-work to resist the heat; and there must be a flap or door in the frame-work, for the purpose of admitting the fuel and stirring the fire. Air must be supplied to the fire, as described above, by a tube leading directly from the external atmosphere to the ash-pit. The ventilation of the room may be effected by an opening into the chimney near the ceiling; and the temperature may be regulated with great precision by a valve placed in this opening, and made to obey the dilatation and contraction of a piece of wire affixed to it, the length of which will always depend on the temperature of the room.—The author contrived the arrangements here described, for the

winter residence of a person threatened with consumption, and the happy issue of that particular case, and of others treated on similar principles, has led him to doubt, whether many of the patients with incipient consumption, who are usually sent to warmer climates, and who die there after suffering hardships on the journey, and distress from the banishment sufficient to shake even strong health,—might not be saved, by judicious treatment in properly warmed and ventilated apartments, under their own roofs, and in the midst of affectionate kindred. And if a boy be almost certainly secured from consumption by being made a miner or a butcher, may we not hope that, when all the influencing circumstances come to be better understood, something of the same immunity may be obtained for persons in all the professions and conditions of civilized society?

It must not be supposed that the remarks made in this section exhaust even nearly the very important subject of temperature as affecting health. The questions of *clothing*, of *hot and cold bathing*, of *exercise*, and others, equally belong to it, but the consideration of them falls under other departments of study.

### *Winds or currents in the atmosphere*

are also phenomena, in a great measure dependent on the law, that lighter fluids rise in heavier. As oil let loose under water is pressed up to the surface and swims, so air near the surface of the earth, when heated by the sun, rises to the top of the atmosphere, and spreads there, forced up by

the heavier air around. This heavier air rushing inwards, constitutes the wind felt at the surface of the earth. The cross currents in the atmosphere, arising as now described, are often rendered evident by the motion of clouds or balloons.

If our globe were at rest, and the sun were always beaming over the same part, the earth and air directly under the sun would become exceedingly heated, and the air would there be constantly rising like oil in water, or like the smoke from a great fire ; while currents or winds below would be pouring towards the central spot, from all directions. But the earth is constantly turning round under the sun, so that the whole middle region or equatorial belt may be called the sun's place : and therefore according to the principle just laid down, there should be over it a constant rising of air, and constant currents from the two sides of it, or the north and south, to supply the ascent. Now this phenomenon is really going on, and has been going on ever since the beginning of the world, producing the steady winds of the northern and southern hemispheres, called *trade winds*, on which in most places within thirty degrees of the equator, mariners reckon almost as confidently as on the rising and setting of the sun himself.

The trade winds, however, although thus moving from the poles to the equator, do not appear on the earth to be directly north and south, for the eastward whirling, or diurnal rotation of the earth, causes a wind from the north to appear as if coming from the north-east, and a wind from the south as if coming from the south-east. This fact



is illustrated by the case of a man on a galloping horse, to whom a calm appears to be a strong wind in his face; and if he be riding eastward, while the wind is directly north or south, such wind will appear to him to come from the north-east, or south-east:—or again, is illustrated by the case of a small globe made to turn upon a perpendicular axis, while a ball or some water is allowed to run from the top of it downwards;—the ball or water will not immediately acquire the whirling motion of the globe, but will fall almost directly downwards, in a track which, if marked upon the globe, will appear not as a direct line from the axis to the equator, that is from north to south, but as a line falling obliquely. Thus then, the whirling of the earth is the cause of the oblique and westward direction of the trade-winds, and not, as has often been said, the sun drawing them after him.

The reason why the trade-winds at their external confines, which are about  $30^{\circ}$  from the sun's place, appear almost directly *east*, and become more nearly *north* and *south* as they approach the central line, is, that at the confine they are like fluid coming from the axis of a turning wheel, and which has approached the circumference, but has not yet acquired the velocity of the circumference; while, nearer the line, they are like the fluid after it has for a considerable time been turning on the circumference, and has acquired the rotary motion there, consequently appearing at rest as regards that motion, but still leaving sensible any motion in a cross direction.

While, in the lower regions of the atmosphere,

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air is thus constantly flowing towards the equator and forming the steady trade-winds between the tropics, in the upper regions there must of course be a counter-current distributing the heated air again over the globe : accordingly, since reasoning led men to expect this, many striking proofs have been detected. At the summit of the Peak of Teneriffe, observations now shew that there is always a strong wind blowing in a direction contrary to that of the trade-wind on the face of the ocean below. Again, the trade-winds among the West-India Islands are constant, yet volcanic dust thrown aloft from the Island of St. Vincent, in the year 1312, was found, to the astonishment of the inhabitants of Barbadoes, hovering over them in thick clouds, and falling, after coming more than 100 miles directly against the strong trade-wind, which ships must take a circuitous course to avoid. Persons sailing from the Cape of Good Hope to St. Helena, have often to remark that the sun is hidden for days together, by a stratum of dense clouds passing southward high in the atmosphere ; which clouds consist of the moisture raised near the equator with the heated air, and becoming condensed again as it approaches the colder regions of the south.

Beyond the tropics, where the heating influence of the sun is less, the winds occasionally obey other causes than those we have now been considering, which causes have not yet been fully investigated. The winds of temperate climates are in consequence much less regular, and are called *variable* ; but still, as a general rule, when-

ever air is moving towards the equator, from the north or south poles where it was at rest, it must have the appearance of an east wind, or a wind moving in the contrary direction to the earth itself, until it has gradually acquired the whirling motion of that part of the surface of the earth on which it is found; and again, when air is moving from the equator, where it had at last acquired nearly the same motion as that part of the earth, on reaching parts nearer the poles, and which have less eastward motion, it continues to run faster than they, and becomes a westerly wind. In many situations beyond the tropics the westerly winds, which are merely the upper equatorial currents of air falling down, are almost as regular as the easterly winds within the tropics, and might also be called trade-winds:—witness the usual shortness of the voyages from New York to Liverpool, and the length of those made in the contrary direction. North of the equator, then, on earth, true north winds appear to be north-east, and true south winds appear to be south-west:—which are the two winds that blow in England for three hundred days of every year. In southern climates the converse is true.

While the sun is beaming directly over a tropical island, he warms very much the surface of the soil, and therefore also the air over it; but the rays which fall upon the ocean around penetrate deep into the mass, and produce little increase of superficial temperature. As a consequence of this, there is a rapid ascent of hot air over the island during the day, and a cooler wind blowing towards

its centre from all directions. This wind constitutes the refreshing *sea-breeze* of tropical islands and coasts. A person must have been among these, to conceive the delight which the sea-breeze brings after the sultry stagnation which precedes it. The welcome ripple shorewards is first perceived on the surface of the lately smooth or glassy sea ; and soon the whole face of the sea is white with little curling waves, among which the graceful canoe, lately asleep on the water, now shoots swiftly along.

During the night a phenomenon of opposite nature takes place. The surface of the earth, then no longer receiving the sun's rays, is soon cooled by radiation, while the sea which absorbed heat during the day, not on the surface only, but through its mass, continues to give out heat all night. The consequence is, that the air over the earth becoming colder than that over the sea, sinks down, and spreads out on all sides, producing the *land-breeze* of tropical climates. This wind is often charged with unhealthy exhalations from the marshes and forests, while the sea-breeze is all purity and freshness. Many islands and coasts would be absolutely uninhabitable but for the sea-breeze.

The peculiar distribution of land in the Asiatic part of the globe, produces the curious effect there of a sea-breeze of six months, and a land-breeze of six months. The great continent of Asia lies chiefly north of the line, and during its summer, the air over it is so much heated, that there is a constant steady influx from the south—appearing



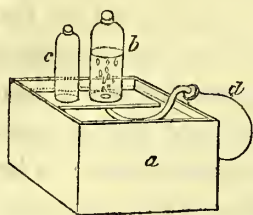
south-west, for the reason given in a preceding page; and during its winter months, while the sun is over the southern ocean, there is a constant land-breeze from the north—appearing, for a like reason, north-east. These winds are called *monsoons*; and if their utility to commerce were to be a reason for a name, they also deserve the name of trade-winds. In early periods of navigation, they served to the mariner the purpose of compass, as well as of moving power; and one voyage outward, and another homeward with the changing monsoons, filled up his year.—On the western shores of Africa and America also, the trade-winds are interfered with by the heating of the land; but much less so than in Asia, and always in accordance with the laws now explained.

The frightful tornadoes, or whirlwinds, which occasionally devastate certain tropical regions, making victims of every ship or bark caught on the waters, and the short gusts or squalls met with every where, are owing to some sudden chemical changes in the atmosphere, not yet fully understood.

### *The Pneumatic Trough and Gasometer*

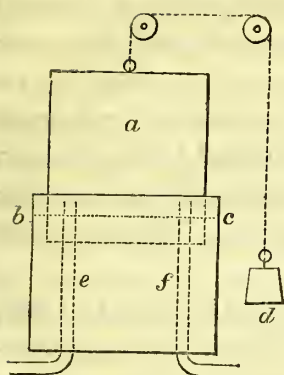
of the chemist are contrivances constantly displaying the truth now under consideration, “that a lighter fluid is pushed up and floats on a heavier.” They are important parts of the apparatus for operating on substances while in the form of air.

The trough *a* may be made of metallic plate, or of wood lined with metal, and of any convenient size. It is nearly filled with water, and has at one



end about an inch under the surface of the water, a shelf, on which jars or vessels, as *b* and *c*, may rest. Any particular air or gas is preserved separate from the atmosphere, by being placed in one of these jars with the mouth downwards. The gas is passed into the jar by the operator first immersing the jar in the trough, so as to fill it with water and to expel the common air from it; and then holding its mouth over the gas while rising under the water from another vessel or pipe:—*d* represents a long-necked vessel, used to contain the ingredients for the production of gases by chemical action. The gas of course rises to the top of the jar *b*, and gradually displaces the water. During the operation of filling, the jar may be supported by the hand or by resting upon the shelf;—in the latter case the gas is allowed to rise into it through a hole in the shelf, provided with a small funnel gaping downwards to catch the air more readily. The shelf may have room on it for many jars, and it may have more holes than one; and if the gas under operation be such that water absorbs or changes it, some other liquid, as mercury, may be used instead of water.

A *gasometer* or *gas-holder*, is merely a larger jar or vessel, as *a*, dipping into water, with its mouth downwards, in a trough of its own shape, *b c*, and so supported or counterpoised by a weight at *d*, over pullies, that very little force suffices to move it up or down. Air forced into it through a pipe *f* opening under it, causes it to rise or float higher



in proportion to the quantity. The air is made to pass from it again when wanted, either through the same tube or through another as *e*.

The huge gasometers, exceeding in size an ordinary house, and containing the supply of gas for the lamps of a town, are vessels suspended as above represented,

in great pits or troughs, filled with water. The gas issues with force proportioned to the downward pressure of the containing vessel, which may be nicely regulated in a variety of ways, and is generally made to equal the action of a column of water of two inches in height; that is to say, such, that a pipe issuing from the gas-holder, and dipping into water at its other end, shall allow gas to escape, if immersed less than two inches perpendicularly.

It would be encroaching on the province of the chemist to treat here particularly of the substances which most generally exist in the aeriform state; but to give an increased interest to the description of the gas apparatus, a few leading facts may be mentioned.

Of about fifty distinct substances known as the materials of our globe, five, when uncombined, and under common circumstances of heat and pressure, exist as airs or gases. The water used to fill the apparatus above described is a compound of two of these substances, *viz.* oxygen and hydro-

*gen.* By directing an electrical current through water, it is gradually decomposed, and from one side, a stream of aeriform oxygen may be received, and from the other a stream of hydrogen. The two gases may be again united to form water, by mixing them in a proper vessel, and passing an electric spark through them. They combine with explosion.

This *oxygen*, so called from its relation to acids, (the name consisting of two Greek words, signifying *acid* and *to form*), has been accounted, for many reasons, the most important substance in nature. It forms eight-ninths, by weight, of the ocean; one-fourth of the atmosphere; and, perhaps, one-fourth of the solid matter of the globe: possibly, therefore, although most persons think of it only as an air or gas, there is not a millionth part of the quantity of oxygen in the world, existing as air. It unites readily with most other substances, and generally with such intense action as to produce the phenomenon of fire or combustion; —the word *combustible* chiefly applies to substances that quickly combine with oxygen.

Oxygen assumes a singular variety of character in its different combinations. Thus with *hydrogen*, it forms water; with *lead*, it forms the substance called *red-lead*; with *nitrogen*, in one proportion, it forms *atmospheric air*, in another proportion, the *nitrous oxide*, or what is called the *laughing gas*, in a third, the acid called *aqua fortis*; with sulphur, it forms the *sulphuric acid* or *oil of vitriol*; with iron, and all metals, it forms their ores called *oxides*; and so forth. But the most important



character in which we know it, is as that ingredient of our atmosphere, without which animals and vegetables cannot live, and fire cannot burn. Oxygen, from this part of its history, was long named *vital* or *pure air*.

Pure oxygen in the state of air is a little heavier than common air; but when holding a quantity of charcoal in solution, it forms aeriform *carbonic acid*, which is nearly twice as heavy as common air, and may be poured out of one vessel into another like water. Carbonic acid is what issues from soda-water, brisk ale, champaigne, &c. while they sparkle. If drawn into the lungs in breathing, it is fatal to life. A charcoal fire left in a close room with sleeping persons, has often been fatal to them, because carbonic acid gas is the product of the combustion. So likewise, houseless wretches in winter, lying down in a brick-maker's field to leeward of a burning heap of bricks, often fall asleep for ever. The famous *Grotto del Cane*, in Italy, is a cavern always full of carbonic acid, which springs into it from below, as water springs into a well, and runs over like water from a well:—it received its name from the circumstance of dogs dying instantly when thrown into it. Carbonic acid rising in fermentation has often proved fatal to persons leaning over the edge of fermenting vats. It is common to see a rat die instantly, in the attempt to run along a plank laid across the mouth of a fermenting tub.

*Hydrogen*, the other ingredient of water, and so called from its relation to *water* (the name consists of the Greek words for *water* and *to form*), when

in the state of air, is sixteen times as light as oxygen. With it balloons are filled. When it holds in solution a certain quantity of carbon or charcoal, it becomes the common gas used for illumination, and is the fire-damp of mines, of which the burning and explosion are so terrible. It forms one-ninth of the ocean, and much of animal and vegetable bodies.

*Nitrogen*, so called from its relation to *nitric acid*, is the third and last substance which we shall mention. It is what remains of the atmosphere when the oxygen is removed. It forms about four-fifths of the atmosphere, one-fourth of animal flesh, and is found in small quantities in other combinations. It will not support life by itself, and therefore formerly was called *azote*: with a larger proportion of oxygen it forms *nitric acid*, or the *aqua fortis* of old.

The last few paragraphs may serve to shew how many of the manipulations of chemistry are directed by the principles of physics or mechanical philosophy; and therefore how essential to the chemist the preliminary study of physics becomes.

## PART III.

OR

## THE PHENOMENA OF FLUIDS.

(CONTINUED.)

SECTION III.—HYDRAULICS—PHENOMENA OF FLUIDS  
IN MOTION.

## ANALYSIS OF THE SECTION.

*Whether the particles of matter exist in the form of solid or fluid, the circumstance does not affect their properties of INERTIA and GRAVITY. Hence liquids and airs, in proportion to their quantity, resist, receive, and impart motion, and have weight and friction, as is true of solids. This is seen in the phenomena of*

1. *Fluids issuing from vessels, or moving in pipes and channels.*
2. *Waves.*
3. *Fluids resisting the motion of bodies immersed in them ; or themselves moving against other bodies.*
4. *Fluids lifted, or moved in opposition to gravity.*

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*“ Fluids issuing from vessels, or moving in channels.”*

WATER admitted to a tube ascending from near the bottom of a reservoir, will rise in it, as already explained, to the level of the liquid surface in the reservoir. If such a tube be afterwards cut off, except a small part at the bottom, then prepared as a jet-pipe, the water will spout from this still to the same height, with a certain deduction for the resistance of the air and friction. Now, as a body shot upwards to any height has that velocity in departing, which it again acquires by falling

back to the same place or level (with a certain deduction for the resistance of the air), as explained at page 93, it follows that fluid issues from any orifice in a reservoir with velocity equal to what a body acquires in falling as far as from the level of the fluid surface in the reservoir to the orifice. By referring then to the law of falling bodies, as explained at page 91, we may learn the velocity of the issue of water in any case, and therefore the quantity delivered by an opening of a given magnitude.

Thus, a body by gravity falls sixteen feet in the first second, with speed gradually increasing, and at the end of the second has a velocity of thirty-two feet per second; therefore a reservoir with an opening of an inch square at sixteen feet below the water's surface, will deliver in one second of time, with a certain deduction for resistance of air, friction, &c., thirty-two feet of a jet of water of an inch square; and according to the same rule, an opening at four times the depth should deliver a double quantity; at nine times the depth, a triple quantity; and so on, as really happens. An inquirer is at first surprised that the quantity should not be quadruple, where the height of column or pressure forcing it out is quadruple, and ninefold when the pressure is ninefold, &c.; but on reflection, he may perceive that the real effects, as stated above, are still exactly proportioned to the causes; for, when only twice as much water is forced out in the same time, there is still an effect four times as powerful, because each particle of the double quantity issues with



twice the force or velocity, and increase of velocity costs just as much force as increase of quantity. Similar reasoning holds with respect to the triple or any other quantities. Because a body shot upward with a double velocity gains a quadruple height (see page 93), the jet issuing with only double velocity from four times the depth, still reaches the level of the surface of the reservoir.

The knowledge of this rule for discharging orifices is of the greatest importance in the construction of water-works, because when joined with other rules assigning the effects of friction, bending, unequal width, &c. in pipes, it ascertains the quantity of water which a conduit of any magnitude, length, and slope, will deliver.

It is a curious fact, that more water issues from a vessel through a short pipe, than through a simple aperture of the same diameter as the pipe; and still more if the pipe be funnel-shaped, or wider towards its inner extremity. The explanation is, that the issuing particles coming from all sides to escape, cross and impede each other in rushing through a simple opening, as is proved by the narrow neck which the jet exhibits a little beyond the opening; but in a tube, this narrowing of the jet cannot happen without leaving a vacuum around the part, and the pressure of the atmosphere, resisting the vacuum, causes a quicker flow. The funnel-shape again leads the water by a more gradual inclination to the point of exit, and thus considerably prevents the crossing among the particles; besides that, because its mouth surrounds

the narrow neck of the jet, it allows that part to be deemed the commencement of the jet.

Another remarkable effect of atmospheric pressure on running liquids is, that in a tube of considerable length descending from a reservoir, it much quickens the discharge. Water naturally falls like any other body with accelerating velocity; but if it so fall in a tube which it fills like a piston, either portions of it below must outstrip portions above, leaving vacuous spaces between, or water from above must be pressed into the tube by some other force than its weight. Now the atmospheric pressure becomes this force, and it prevents a vacuum, partly by impelling water more rapidly into the top of the tube, and partly by resisting the discharge from below. The forcing in of the water at the top of the tube causes that depression of the water-surface in the reservoir over it, which becomes more conspicuous as the depth in the reservoir diminishes, and at last is a deep hole in the water extending far into the tube, and sometimes even, as in a common funnel, extending quite through.

The friction or resistance which fluids suffer in passing along pipes is much greater than might be expected. It depends on the cohesion of the particles to the surface of the pipe and among one-another, and on the particles near the outside being constantly driven from their straight course by the irregularities in the surface of the pipe. An inch tube of two hundred feet in length, placed horizontally, is found to discharge only a fourth part of the water which escapes by a simple

aperture of the same diameter. Air passing along tubes is still more retarded. A person who erected a great bellows at a waterfall, to blow a furnace two miles off, found that his apparatus was totally useless. When gas-lights were first proposed, some engineers feared that the resistance by friction to the passing air would be fatal to the enterprize.

Higher temperature in a liquid increases remarkably the quantity discharged by an orifice or pipe,—apparently by diminishing that cohesion of the particles which exists in certain degrees in all liquids, and affects so much their internal movements. The addition of 100 degrees of heat will in certain cases nearly double the discharge.

The flux of water through orifices under uniform circumstances is so steady, that before the invention of clocks and watches, it was employed as a means of measuring time. The vessels were called *clepsydræ*. That of Ctesibius is famous, in which the issuing water took the form of tears from the eyes of a figure, deploring the rapid passing of precious time; and these tears being received into a fit vessel, gradually filled it up and raised another floating figure, who pointed to the hours marked on an upright scale. This vessel was daily emptied by a syphon, when charged to a certain height, and its discharge worked machinery which told the month and the day.—The common hour-glass of running sand is another modification of the same principle, with this remarkable difference, however, that depth of the sand does not quicken the flux.

The progress of water in an open conduit, such

as the channel of a river or aqueduct, is influenced by friction, &c. in the same manner as in close pipes. But for this, a river like the Rhone, drawing its waters from an elevation of 1,000 feet above the level of its mouth, would pour them out, with the velocity of water issuing from the bottom of a reservoir 1,000 feet deep; that is to say, at the rate of about 170 miles per hour. The ordinary flow of rivers is about three miles per hour, and their channels slope three or four inches per mile.

The velocity of a water current is easily ascertained by immersing in it an upright tube, of which the bottom bent at right angles becomes an open mouth turned towards the stream. The water in the tube will stand above the surface of the stream, as much as would be necessary in a reservoir, according to the explanation given above, to

cause a velocity of jet equal to the velocity of the stream. A modification of this contrivance may be made to measure the velocity of the wind.—A common mode of telling the velocity of an open stream, is to observe with a stop-watch the progress of a body floating in some part of it from which its medium speed may be known: and knowing that speed and the depth and width of the channel, the quantity delivered in a given time becomes a matter of simple calculation. The speed of the wind may be ascertained by observing how long the shadow of a cloud takes to pass across a field of known dimensions.

The friction of water moving in water is such,



that a small stream directed through a pool, with speed enough to rise over the opposite bank, will soon empty the pool. Extensive fens have been drained on this principle. The friction between air and water is also singularly strong, as is proved on a great scale by the magnitude of the ocean-waves, which are consequences of it; and on a small scale by the amusing experiment of making a light round body dance or play upon the summit of a water-jet,—a chief cause of its remaining there being, that the current of air which rises around the jet by reason of the friction, presses it inwards again, whenever it inclines to fall over. Oil thrown upon the surface of water, soon spreads as a film over it, and defends it from the farther contact and friction of the air. If oil be thus spread at the windward side of a pond where the waves begin, the whole surface of the pond soon becomes as smooth as glass; and even out at sea, where the commencement of the waves cannot be reached, oil thrown upon them smoothes their surface to leeward of the place, and prevents their curling over or breaking. It is said that boats having to reach the shore through a raging surf, have been preserved by the crews first spilling a cask of oil in the offing.

The most magnificent examples that ever existed, or probably ever will exist, of artificial water-courses, were the aqueducts of ancient Rome, about twenty in number. Several of them exceeded forty miles in length, passing through hills in their way, and resting on tiers of splendid

arches across the vallies. They were constructed of such durable materials, and so skilfully, that the principal of them remain perfect to this day. Considered as one object, they rank, in point of magnitude, with any other work of human labour, not excepting the pyramids of Egypt.

While the aqueducts are cited as specimens of grandeur, we may mention the fountains in the gardens of France and Italy, as specimens of beauty. Those at Versailles are well known. In them the most magical effects are produced by varying the ways in which water is made to spout from orifices. In one place it is seen darting into the air as a single upright pillar: in others many such pillars rise together, like giant stalks of corn: sometimes, an inclination given to the jets, makes them bend so as to form beautiful arches, of which a portion appear as the roofs of apartments built of water, while others mingle together with endless variety: here and there water-throwing wheels send out spiral streams, and hollow spheres with a thousand openings are the centres of immense bushes or trees of silvery boughs. Such effects, amidst cascades, smooth lakes, and scenes of lovely landscape, constitute a whole as enchanting, perhaps, as art by moulding nature has ever produced.

“ *Waves.*”

The form, magnitude, and velocity of waves, are subjects admitting of deep mathematical research; and are rendered the more interesting, because certain phenomena of *sound* and *light* are

of kindred nature. Here, however, they must be treated with great brevity.

A stone thrown into a smooth pond, causes a succession of circular waves to spread from the spot where it falls as a common centre. They become of less elevation as they expand, and each new one is less raised than the preceding, until gradually the liquid mirror becomes again perfect as before. Several stones falling at the same time in different places, cause crossing circles, which, however, do not disturb the progress of one-another,—a phenomenon seen in beautiful miniature at each leap of the little insects which cover the surface of our pools in the calm hours of summer.—The rationale of the formation of waves in such cases is as follows. When the stone falls into the water, because the liquid is incompressible, a part of it is displaced laterally, and becomes an elevation or circular wave around the stone. This wave then spreads outwards in obedience to the laws of fluidity, already explained, and the circle is seen to widen. In the mean time, where the stone descended, a hollow is left for a moment in the water, but owing to the surrounding pressure, is soon filled up, chiefly by a sudden rush from below. The rising water does not stop, however, at the exact level of that around, but like a pendulum sweeping past the centre of its arc, it rises almost as far above the level as the depression was deep. This central elevation now acts as the stone did originally, and causes a second wave, which pursues the first; and when the centre subsides, like the pendulum still, it sinks again almost

as much below the level as it had mounted above: hence it has to rise again, again to fall, and so on for many times, sending forth a new wave at each alternation. Owing to the friction among the particles of the water, each new wave is less raised than the preceding, and at last the appearance dies away.

A wave passing through any gap or opening, spreads from it as a new centre; and a wave coming against a perpendicular surface of wall or rock, is completely reflected from this, and acquires the appearance of coming from a point as far beyond the reflecting surface, as its real origin or centre is distant on the side where it is moving.

So absolutely level is a liquid surface, and so sensitive or mobile, that the effect of any disturbing cause is perceived at great distances. A boat rowed across a still lake, ruffles its surface to a great extent; and although the widening waves become at last such gentle risings as not to be perceptible to the eye, they still produce a rippling noise where they fall among the pebbles on the shore. In seas liable to sudden but partial hurricanes, the roar of breakers on distant coasts often tells of the storm which does not otherwise reach them. The author once, in the eastern ocean, had an opportunity of contemplating waves of extraordinary magnitude rolling along during a gloomy calm, and therefore with unbroken surface, appearing like billows of molten lead. At that very time, about a hundred and fifty miles to the north-east, four of the finest ships of the India Company were perishing in a storm.—In the polar



seas, which are comparatively tranquil, because partially defended from the wind by the floating islands of ice, a few sudden waves are occasionally observed, and quickly all is calm again. Such a phenomenon announces, that the occurrence described at page 314 has happened somewhere, of an island of ice turning over, when the place of its centre of gravity is changed by partial melting.

The common cause of waves is the friction of the wind upon the surface of the water. Little ridges or elevations first appear, which by continuance of the force, gradually become loftier and broader, until they are the rolling mountains seen where the winds sweep over a great extent of water. The heaving of the bay of Biscay, or still more remarkably, of the open ocean beyond the southern capes of America and Africa, exhibits one extreme, and the stillness of the tropical seas, which are sheltered by near encircling lands, exhibits the other. In the vast archipelago of the east, where Borneo, and Java, and Sumatra lie, and the Molucca islands and the Philippines, the sea is often fanned only by the land and sea breezes, and is like a smooth bed, in which these islands seem to repose in bliss—islands in which the spice and perfume gardens of the world are embowered, and where the bird of paradise has its home, and the golden pheasant, and a hundred other birds of brilliant plumage, among thickets so luxuriant, and scenery so picturesque, that European strangers find there the fairy land of their youthful dreams. —One who has visited these islands in his early

days, may perhaps be pardoned for thus adverting to their beauties.

In rounding the Cape of Good Hope, waves are met with, or rather a swell, so vast, that a few ridges and a few depressions occupy the extent of a mile. But these are not so dangerous to ships as what is termed a *shorter* sea, with more perpendicular waves. The slope in the former is comparatively gentle, and the rising and falling are much less felt; while among the latter, the sudden tossing of the vessel is often destructive. When a ship is sailing directly before the wind, over the *long swell* now described, she advances as if by leaps; for as each wave passes, she is first descending headlong on its front, acquiring a velocity so wild that she can scarcely be steered; and soon after, when it has glided under her, she appears climbing on its back, and her motion is slackened almost to rest, before the following wave arrives. To a passenger perched at such a time on the extremity of the bowsprit, and looking back on the enormous body of the ship, with perhaps its thousand of a crew, a hundred feet behind him, heaved by these billows as a cork is on a ruffled lake, the scene is truly sublime. When a coming wave lifts the stern and in the same degree depresses the bow, he is deep in the hollow or valley between the waves, and sees only the ship rushing headlong down towards him as if to be ingulphed; but soon after, when the stern is down, and the bow is raised, he looks from his station in the sky upon an awful scene beneath him and around.

The velocity of waves has relation to their mag-

nitude. The large waves just spoken of, proceed at the rate of from thirty to forty miles an hour. —It is a vulgar belief that the water itself advances with the speed of the wave, but in fact the *form* only advances, while the *substance*, except a little spray above, remains rising and falling in the same place, with the regularity of a pendulum. A wave of water, in this respect, is exactly imitated by the wave running along a stretched rope when one end is shaken; or by the mimic waves of our theatres, which are generally undulations of long pieces of carpet, moved by attendants. But when a wave reaches a shallow bank or beach, the water becomes really progressive, for then, as it cannot sink directly downwards, it falls over and forwards, seeking the level.

So awful is the spectacle of a storm at sea, that it generally biasses the judgment; and, lofty as waves really are, imagination pictures them loftier still. Now no wave rises much more than ten feet above the ordinary sea-level, which, with the ten feet that the surface afterwards descends below this, give twenty feet for the whole height, from the bottom of any water-valley to an adjoining summit. This is easily verified by a person who tries at what height on a ship's mast the horizon remains always in sight over the top of the waves —allowance being made for accidental inclinations of the vessel, and for her sinking in the water to considerably below her water line, at the time when she reaches the bottom of the hollow between the two waves. The spray of the sea, driven along by the violence of the wind, is of course much

higher than the summit of the liquid wave ; and a wave coming against an obstacle, or entering a narrowing inlet, may dash to an elevation much greater still. At the Eddystone light-house, which is about ninety feet high, placed on a solitary rock ten miles from the land, when a surge breaks which has been growing under a storm all the way across the Atlantic, it often dashes to 100 feet above the lantern at the summit.

The magnitude of waves is well judged of when they are seen breaking on an extended shore or beach. In the deep sea the wave is only an elevation of the water, sloping on either side ; but as it rolls towards the shore, its front becomes more and more perpendicular, until at last it curls over and falls with its whole weight, and when several miles of it break at the same instant, its force and noise may shake the country around.

Along the east, or Coromandel Coast of India, at certain seasons, vast waves are constantly breaking ; and as there are no good harbours there, communication between the sea and land is rendered impossible to ordinary boats. The natives of the coast, at Madras, for instance, have hence become almost amphibious. They reach ships beyond the breakers by the help of what are called *catamarans*, consisting of three small logs of wood tied together. On these they secure themselves, and boldly advance up to the coming wall of water, which they shoot into, and rise to the smooth surface beyond it, like water-fowls after diving. Boats unsuited to the breakers often perish in them. The author of this work had gone on shore



with a watering party on the coast of Sumatra, and during the hours spent there, a swell had arisen in the sea, which on their return was already bursting along the beach and across the river's mouth in lofty breakers. The boat in which he happened to be, regained the high sea in safety, but a larger boat which followed at a short distance was overwhelmed, and an officer and part of the crew perished.

There is a phenomenon observed at the mouths of many great rivers, called the *Boar*, which has resemblance to a wave. When the tide returning from the sea meets the outward current of the river, and both have the force which in certain situations belongs to them, the stronger mass from the ocean assumes the form of an almost perpendicular wall, moving inland with resistless sweep. This is called the boar. It is in fact the great sea-wave of the tide, produced twice a day by the attraction of the moon, rolling in upon the land and inlets, where contracting channels concentrate its mass. In the different branches of the Ganges the boar is seen in a remarkable degree. Its roaring is heard long before it arrives. Smaller boats and skiffs cannot live where it comes; and as it passes the city of Calcutta, even the large ships at anchor there are thrown into such commotion, as sometimes to be torn away from their moorings.—The nature and effects of this boar are strikingly illustrated upon certain coasts where extensive tracts of sand are left uncovered at low water. In such situations, of which there are many on the western shores of Britain, the returning tide is

seen advancing with steep front, and with such rapidity, that the speed of a galloping horse can scarcely save a person who has incautiously approached too near. Many, every year, are the victims of temerity or ignorance on these treacherous plains.

In the end of the year 1831, on the low flat coast of the Indian peninsula, north of Madras, one great wave of the kind now described was produced during a very high spring-tide of midnight, by an extraordinary wind, and spread ten miles in upon the inhabited land. It had retired with the ebbing tide before morning, but the next day's sun disclosed a scene of devastation rarely matched. Amidst the total wreck of the villages and fields, there lay the drowned carcasses of more than ten thousand human beings, mixed with those of elephants, horses, bullocks, wild tigers, and the other inhabitants of the land.

It has been proposed lately to construct *submarine boats*, or vessels calculated to swim so deep in the water as to be below the superficial motion of the waves, and therefore beyond the influence of storms at the surface. Such a boat has been tried with considerable success; and men's increasing familiarity with submarine matters since the invention of the diving-bell, may ultimately lead to improvements rendering the submarine vessel, for certain purposes, commodious and safe.

“ *Fluids resisting the motion of bodies immersed in them, or themselves moving forcibly against other bodies.*” (See the Analysis.)

The same force is required to give, or to take away, or to bend motion, in a fluid, as in an equal quantity of solid matter. A pound of water enclosed in a bladder is not more easily thrown to a given height than a pound of ice, or of lead; nor, if falling into the scale of a weighing beam, does it require less as a counterpoise; nor if made to revolve at the end of a sling, does it render the cord less tight.

A convenient measure of the force of moving water on an obstacle, or of the resistance of still-water to a moving body, exists in the facts already explained, that the pressure of a known height of fluid column produces from an orifice a certain velocity of jet, while conversely, that jet, or a current of equal speed, directed against the orifice, supports the column. The impulse given or received, therefore, by a flat surface in water, such as the vane of a water-wheel, whether that of a steam-boat pressing against the water, or that of a corn-mill pressed by it, is measured by the weight of the column alluded to, the height of which is, according to the velocity and the breadth or diameter, according to the breadth or extent of the solid surface concerned. This estimate supposes that the pressure of or upon the surface is direct; if it be oblique, there is a diminution according to the rule given under the head of "resolution of forces."

Many persons, looking carelessly at the subject of fluid resistance, would expect, that if a body, as a boat, moving through a fluid at a given rate meets a given resistance, it should just meet double

resistance when moving twice as fast. Now the resistance is four times greater with a double rate.

This fact is but another example of a principle already explained, and when more closely examined, is easily understood. A boat which moves one mile per hour, displaces or throws aside a certain quantity of water, and with a certain velocity;—if it move twice as fast, it of course displaces twice as many particles in the same time, and requires to be moved by twice the force on that account; but it also displaces every particle with a double velocity, and requires another doubling of the power on this account: the power then being doubled on two accounts, becomes a power of four. In the same manner with a speed of three, three times as many particles are moved, and each particle with three times the velocity; therefore, to overcome the resistance, a force of nine is wanted; for a speed of four, a power of sixteen; for a speed of five, a power of twenty-five; and so forth: the relation being that which mathematicians indicate by saying *that the resistance increases as the square of the speed*. The corresponding numbers, up to a speed of ten, are as here shewn,

Speed.....	1	2	3	4	5	6	7	8	9	10
Corresponding resistance... }	1	4	9	16	25	36	49	64	81	100

Thus, even if the resistance at the bow of a vessel were all that had to be considered, the force of one hundred horses would only drag the vessel ten times as fast as the force of one horse. But there is another important element in the calculation,



*viz.* the lessening, as the vessel's speed quickens, of the usual water-pressure on the stern,—which pressure, while she is at rest, is equal to the pressure on the bow; and the force therefore required to produce an increased velocity is still considerably greater than as noted in the table.

There is not a more important truth in physics than the law of fluid resistance to moving bodies, here treated of; it explains so many phenomena of nature, and becomes a guide in so many matters of art. We will now set forth some interesting examples.

It explains at what a heavy expense of coal high velocities are obtained in steam-boats. If an engine of about 50-horse power would drive a boat 7 miles an hour, two engines of 50, or one of 100, would be required to drive it 10 miles, and three such to drive it 12 miles; even supposing the increased resistance at the bow, as already stated, to be the measure of the whole work done, which it is not, and that engines worked to the same advantage with a high velocity as with a low, which they do not.—For the same reasons, if all the coal which a ship could conveniently carry were just sufficient to drive her 1,000 miles, at the rate of 12 miles per hour, it would drive her more than 3,000 at a rate of 7 miles per hour; and more than 6,000 at a rate of 5 miles per hour. This is a very important consideration, for persons concerned in steam navigation to distant parts.

The same law shews the folly of putting very large sails on a ship; the trifling advantage in point of speed by no means compensating for the

additional expense of making and working the sails, and the risk of accidents in bad weather. The ships of the prudent Chinese have not, for the same tonnage, one-third so much sail as those of Europeans, and yet they move but a little slower on that account. A European ship under jurmasts does not lose so much of her usual speed as most people would expect.

This law explains also why a ship glides through the water one or two miles an hour when there is very little wind, although with a strong breeze she would only sail at the rate of eight or ten miles. Less than the 100th part of that force of wind which drives her ten miles an hour, will drive her one mile per hour, and less than the 400th part will drive her half a mile. Thus also, during a calm, a few men pulling in a boat can move a large ship at a sensible rate.

These considerations shew strikingly of what importance to navigation it might be to have, as a part of a ship's ordinary equipment, one or two water-wheels (or ready means of forming them), to be affixed upon the ship's side when required, like the paddle-wheels of a steam-boat, and by turning which the crew might easily deliver themselves from the tedium, or even disastrous consequences of a long calm at sea.—This idea occurred to the author while in a ship completely becalmed for weeks on the Line : during which wearisome period, the breezes were often seen roughening the water a mile or two farther on ; and any means that could have enabled the ship's company to advance her that little distance might have saved

the delay. The wheels might be driven by connexion with the capstan, at which, under such circumstances, the crew would most willingly work. Delay in a large vessel often costs hundreds of pounds per day, and may retard the execution of important projects.—But the propelling of the ship in a calm seems by no means the most important purpose which such wheels might serve. If from disease, fatigue, or other cause, the crew were inadequate to existing necessities, two wheels affixed to the extremities of an axis crossing the ship might be equivalent in many cases to additional hands, or to a steam-engine of great power; for when acted upon by the water as the ship sailed, they would turn with the force of water-wheels on shore, and might be made to move the pumps, to hoist the sails, and to do any work which a steam-engine could perform. Many a gallant vessel has perished because the exhausted crew could no longer labour at the pumps, where such water-wheels as now contemplated, or a wind-mill-wheel in the rigging would have performed the duty most perfectly.

The law that resistance to a body moving in a fluid increases in a greater proportion than the speed of the body, applies where the fluid is aeriform, as well as where it is liquid.

A bullet shot through the air with a double velocity, for the reason assigned above, experiences four times as much resistance in front, as with a single velocity: the motion is retarded also by the diminution of the usual atmospheric pressure of

15lbs. per inch on the posterior surface, which diminution is proportioned to the speed. It is farther true, that when the velocities of bodies moving in air are very great, the resistance increases in a still quicker ratio than in liquids,—probably because the compressibility of air allows it to be much condensed or heaped up before the quick moving body. It is useless to discharge a cannon ball with a velocity exceeding 1,200 feet in a second, because the powerful resistance of the air to any velocity beyond that, soon reduces it to that at least.

The rule of reciprocal action between a solid and fluid, now explained, holds equally when the fluid is in motion against the solid, as when the solid moves through the fluid.

If a ship be anchored in a tide's way, where the current is four miles an hour, the strain on her cable is not one-fourth part so great as if the current were eight miles.

A wind moving three miles an hour is scarcely felt; if moving six miles, it is a pleasant breeze; if twenty or thirty miles, it is a brisk gale; if sixty, it is a storm; and beyond eighty, it is a frightful hurricane, tearing up trees and destroying every thing.

Supposing the wind to move one hundred miles per hour, there are one hundred times as many particles of matter striking any body exposed to it, as when it moves only one mile per hour, and each particle strikes moreover with one hundred times the velocity or force, so that the whole in-



crease of force is a hundred times a hundred, or ten thousand. This explains how the soft invisible air may by motion acquire force sufficient to unroof houses, to level oaks which have been stretching their roots around for a century, and in some West-India hurricanes, absolutely to brush every projecting thing from the surface of the earth.

The law of rapidly increasing resistance assigns a limit to many velocities, both natural and artificial.

It limits the velocity of bodies falling through the air. By the law of gravity, a body would fall with a constantly accelerating speed, but as the resistance of the air increases still more quickly than the speed, at a certain point, this resistance and the gravity balance each other, and the motion becomes uniform.

The *parachute*, by means of which a person may safely descend to the earth from a balloon at any elevation, furnishes a good example. This contrivance resembles a large flat umbrella. The aeronaut attaches himself underneath it, and when it is let loose from the balloon, he is partly supported by the resistance which its broad expanse experiences in falling through the air, and falls, therefore, in a corresponding degree more slowly. After the first second or two, for the reason stated above, it descends with a uniform motion ; and its breadth is generally made such, as to allow a velocity of about eleven feet in a second, or that

(1.)

2 H

which a man acquires in jumping from a chair two feet high.

No ship sails faster than fifteen miles in an hour.—And it is because the resistance to be overcome in steam-carriages on rail-ways, *viz.* their friction, does not increase with their velocity like the fluid resistance to steam-boats, that the speed of the former may so much exceed that of the latter.

No fish swims with a velocity exceeding twenty miles an hour; not the dolphin, when shooting ahead of our swiftest frigates, nor the salmon, when darting forward with speed which lifts him over a waterfall.

And the flight of birds through the thin air has a limited celerity. The crow, when flying homewards against the storm, cannot face the wind in the open sky, but skims along the surface of the earth in the deep vallies, or wherever the swiftness of the wind is retarded by terrestrial obstructions. The great albatross, stemming upon the wing the current of a gale so as to keep company with a driving ship where the air is passing at the rate of a hundred miles an hour, often takes shelter momentarily under the lee-side of the lofty billows. The bird called the *stormy petrel* abides chiefly in the midst of the Atlantic Ocean, but the irresistible violence of the wind occasionally sweeps it from the waves, and causes its appearance on the western shores of Europe. Vessels from the high sea, approaching a coast from which the wind blows, generally become resting-places to exhausted land birds, driven off the shore by wind which they have not had strength of wing to stem;—sad evi-

dences of the myriads which are constantly perishing where no resting-place is found, and where no human eye notes their fate.

The action or resistance between a meeting fluid and solid, is influenced by the shape of the solid.

This follows from what has already been said of direct and oblique impulse. If a flat surface directly opposed to the fluid experience a certain resistance, a projecting surface like that of a sphere or short wedge is resisted in a less degree, and a concave surface in a greater. The explanation is, that a flat or plane surface throws the particles of fluid almost directly outwards from its centre to its circumference, and therefore with greater velocity, while the convex or wedge-like surface, although displacing them just as far, still does so more slowly, and therefore with less expenditure of force, in proportion to the obliquity of surface, or as its point is in advance of its shoulder or broadest part; and a concave surface must give to some of the particles a forward as well as a lateral motion. The shape of the hinder part of a solid moving through a fluid is of importance for corresponding reasons.

The following are instances of projecting or wedge-like surfaces, intended to diminish the resistance. Fishes are wedge-like both before and behind, their form being modified, however, in relation to other objects than mere speed of motion. Birds are so also; and they stretch out their necks while flying, so as to make their form perfect for

dividing the air. In the form of the under part of boats and ships, men have, in a degree, imitated the shape of fishes. The light wherries which shoot about upon the surface of the Thames, appear the very essence of what imagination can picture of form combining utility and grace. There are boats used in China called *snake-boats*, which are only a foot or two broad, but perhaps a hundred feet in length, and when moved, as they often are, by nearly a hundred rowers, their swiftness is extreme. The problem of which it is the object to assign for a ship's hull or bottom the best possible form that she may have speed of sailing, is not yet completely solved; so that a kind of empiricism prevails in the matter, and very unexpected results often arise. Yet the subject merits much attention, for when vessels have to chase and to flee, speed becomes of the greatest importance; and at all times the sailor's heart swells with delight to find his well-beloved vessel performing well.

The following instances exhibit the mutual influence of meeting solids and fluids, where the surface of the solid is plane or concave.—In a water-wheel, whether the water be moving against the wheel, as is the case where a stream acts to drive machinery, or the wheel be moving against the still water, as in the case of the paddle-wheels of a steam-boat, the extended faces of the vanes or float-boards give or receive a powerful impulse. When a wheel with float boards has its lower part merely dipping into a stream of water, to be driven by the momentum, it is called an *under-shot wheel*; when the water reaches the wheel near the middle



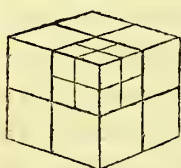
of its height, and turns it by falling on the float-boards of one side as they sweep downwards in a curved trough fitting them, the modification is called a *breast-wheel* ; and when the float-boards are shut in by flat sides, so as to become the bottoms of a circle of cavities or buckets surrounding the wheel, into which the water is allowed to fall at the top of the wheel, and to act by its weight instead of its momentum, the modification is called the *overshot-wheel*. To have a maximum of effect from wheels moved by the momentum of water, they are generally made to turn with a velocity about one-third as great as that of the water : and wheels moved by the simple weight of water usually have their circumference turning with a velocity of about three feet per second. The subject of water-wheels is one of the most important in practical mechanics ; for moving water performs a great deal of labour for man.

Oars for boats are made flat, and often a little concave, that the mutual action between them and water may be as great as possible. The webbed feet of water-fowl are oars : in advancing, they collapse like a shutting umbrella, but open outwards in the thrust backwards, so as to offer a broad concave surface to the water. The expanded wings of birds are in like manner a little concave towards the air which they strike. The sails of ships, when they are receiving a fair wind, are left slack so as to swell and become hollow.

The resistance between a meeting solid and fluid being nearly proportioned to the breadth of the

solid, it follows that large bodies, because containing more matter in proportion to their breadth or surface than smaller bodies of similar form, are less resisted, in proportion to their weights, than smaller bodies.

The science of measures tells us that a bullet or other solid of two inches diameter, has eight times as much matter in it as a similar solid of one inch diameter, while it has only four times the breadth or surface. Thus, by putting eight dice or little



cubes together, as here represented, we have a larger cube, of which, compared with a single die, the edge is evidently *twice* as long, the surface *four* times as great, and the quantity of matter *eight* times as great:—again, *twenty-seven* dice similarly put together form a cube with sides *three* times as long, and the surface *nine* times as great;—and sixty-four dice form a cube with sides *four* times as long, and surface *sixteen* times as great. All solids similar have to each other this kind of relation, which, in the language of the science of quantity, is called the relation of cubes: they are said to be to each other as the cubes of any of their corresponding lines. Hence, if a bullet of eight pounds and a bullet of one pound be shot off with equal velocity, because that of eight pounds has only half as much surface in proportion to its weight, and therefore to its motal inertia or force, as the other, it will go much farther than the other.

This important rule explains why shells and

large shot may be thrown four or five miles, while smaller cannon-balls, musket-bullets, pistol and swan shot, and the common small-shot of the sportsman, all of which are generally discharged from their respective pieces with the same commencing velocity, have a shorter range, as the size of the projectile is less. Even water is sometimes thrown from a gun or powerful syringe to stun birds, that they may be obtained with uninjured plumage ; but it soon divides in the air so minutely that it reaches only to a short distance.

Water falling through the air from a great height, goes on suffering a gradual division into smaller and smaller portions, which at last may be said to be nearly all surface ; and then the resistance of the air lets them fall very slowly indeed. The relation of the size and resistance is well shewn by the difference of celerity in the descent of a minute fog, a drizzling mist, and common rain. The toy called the *water-hammer*, is merely a little water enclosed in a tube exhausted or empty of air ; and when, by turning the tube, the water is made to fall from one end to the other, as there is no air to impede or divide it in its descent, it falls as one mass, and makes a sharp noise like the blow of a hammer.

The same law explains why a spider's thread or a single filament of silk floats so long in the air before it falls ;—why there is almost constantly suspended in the air, wherever active man resides, that immense quantity of very minute solid particles, which, when rendered visible by the sun's light passing directly through them, are called

motes in the sunbeam—particles which are constantly settling on household furniture, and rendering necessary the daily operation of dusting or cleaning ;—why the fine dust sent aloft during the eruption of volcanoes is often carried by the wind to a distance of hundreds of miles ;—why in the deserts of Africa the strong winds often transport fine sand from place to place, overwhelming caravans, and forming new mountains, which succeeding blasts are again to lift ;—why in the bottom of a river, or in a tides-way, fine mud is found where the current is slow ; sand where it is quicker ; pebbles, or large stones, where it is quicker still ; while in rapids and water-falls, only massy rocks can resist the fluid force. Now rock, pebble, sand, and mud, may all be the same material in portions of different magnitude.

This law explains the operation of *levigating*, by which substances insoluble in water are obtained in the state of a very fine powder. Any such substance is first ground or powdered in the ordinary way, and mixed with water. The grosser parts then soon fall to the bottom, while the fine dust remains longer suspended. This is afterwards obtained separatively by pouring the liquid which bears it into another vessel, and allowing more time for the slow subsidence. The fine powder of flint used in the manufacture of porcelain is obtained by levigation ; as is also that of calamine stone, and other powders used in medicine and various arts.

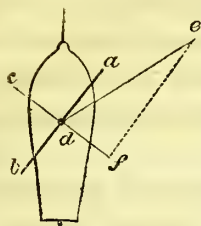
This law further explains how, by means of air or water, bodies of different specific gravities, al-



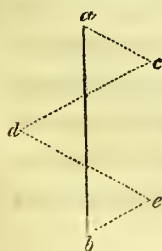
though mixed ever so intimately, may be easily separated. If pieces of cork and lead be let fall together through the air, the lead will reach the ground first, and may be swept away before the cork arrives; but in a vacuum the whole would reach the ground at the same time, as is proved by the common experiment of the guinea and feather falling in the exhausted receiver of an air-pump. Again, when a mixture of corn and chaff, as it comes from any threshing-machine, is showered down from a sieve in a current of air, the chaff being longer in falling, is carried farther by the wind, while the heavier corn falls almost perpendicularly. The farmer, therefore, by *winnowing* in either a natural or artificial current of air, readily separates the grain from the chaff; and, if he desire it, may even divide the grain itself into portions of different quality. Similar to the operation of separating chaff from corn by wind, is that of separating sand or mud from gold-dust by water:—the soil containing gold-dust is first spread on a flat surface, over which a current of water is then made to pass; which current carries away the lighter rubbish, and leaves the gold. If a mass of metal be affixed on the end of a rod of wood, the rod then, whether simply falling through the air, or advancing as an arrow, will follow the heavier metal as its point. The cork of a shuttlecock is always foremost for the same reason.

The instances enumerated under this head serve to shew how many and varied the results may be which flow from a single principle.





wind be represented, as to direction and strength, by the line  $e d$  approaching the sail  $a b$ , it will act on the sail as if it came from  $f$ , but with the smaller force  $f d$ , instead of the whole force  $e d$ . The effect, therefore, is the same as if the sail were pulled by a rope  $d c$ . We see in this, how a ship can be made to sail in a certain degree against the wind:—for all the sails being adjusted so as to receive the wind in the direction here shewn, they all act to produce the same result as if ropes were pulling from each in the direction  $d c$ ; and a force like  $f d$ , or a rope like  $d c$ , urging sideways as well as forwards—as instanced in the tow-rope of a canal boat,—makes the vessel advance rapidly forward, but scarcely at all sideways, because the form of vessels causes them to pass forward at least twenty times more easily with their sharp bow, than sideways with their long broad keel; and therefore a force urging equally sideways and forwards, makes a ship advance twenty miles in the direction of her keel, that is forwards, for one mile which she deviates sideways.—The deviation sideways, which in sailing vessels must take place to a certain extent whenever the wind is at all oblique, is called the *lee-way*.



A vessel having to sail from  $b$  to  $a$ , while the wind blows directly against her course, or from  $a$  to  $b$ , is obliged to sail *close to the wind*, as represented in last page, first perhaps to  $e$ , as represented by this figure, with the left

or larboard side to the wind, then to *tack*, as it is called, or turn round, at *e*, and to sail to *d*, with the right or starboard side to the wind : then to go on the larboard tack again to *c*, and from thence to the port at *a*.

In making way against a *contrary wind*, the sails of a ship are pointed so nearly edgeways to the wind, that unless very flat, a great portion of their surface becomes useless. The Chinese manner of rigging is, in this respect at least, superior to the European ; for in it bamboo reeds attached across the sails, render them as flat as boards. When a Chinese ship has her sails pointing edgeways to a spectator, he only sees the masts which support them.

The reason why a ship with several masts generally sails faster when the wind is more or less from a side, than when directly astern, is, that in the former case all the sails are acting, although individually not to the best advantage, while, in the latter, the sails in front are becalmed by those behind them. A ship with a side-wind may move faster than the wind itself, as is often true of the outer extremities of a windmill's vanes. A corresponding relation of motions is observed when a slippery wedge is forced out two or three inches laterally from its place, by a weight which descends only one inch perpendicularly.

The law now under consideration explains the action of the *rudder* of ships,—that contrivance, by which a single steersman can direct the course of an enormous vessel through rocks and shoals, more steadily and safely than an adroit charioteer



can guide his tiny vehicle on a common road. The helm or rudder is a flat projection from the stern-post of the ship, turning on strong hinges, in the manner of a door or gate, and moved by a beam or lever called the *tiller*, which proceeds from it forward to where the steersman stands. In small vessels the tiller is above the deck, and the steersman applies his hand directly to it; but in large ships it is below, and is moved by ropes, rising from it to the *wheel* on the deck, where the steersman stands with the compass before him. While



the rudder points directly astern, as to *a*, like a continuation of the keel and stern-post, it does not affect the vessel's course; but if it be inclined ever so little to one side, as to *b* on the left or *larboard* side, the water immediately acts on it in the direction *c b*, perpendicular to its surface, and pushes the stern to the right or *starboard* side,—an action equivalent to pulling the bow to the left or *larboard*.

It is possible to make a ship or boat steer itself, by placing a powerful vane on the mast-head, and connecting it with the tiller-ropes by two projecting arms from its axis. If it were desired to make the ship sail directly before the wind, the tiller-ropes would be fixed to the arms of the vane so that the helm should be in the middle position, when the vane were pointing directly forward: should the vessel then from any cause deviate from her course, the vane by its changed position with respect to her, would have produced a corresponding change on the position of the helm, just such as to bring

her back to her course. Again, it is evident that, by adjusting such a vane and rudder to each other in different ways, any other desired course might be obtained, and which would alter only with the wind. The vane, to have the necessary power, would require to be of large size; it would be a wide hoop, for instance, with canvass stretched upon it; and the rudder, to turn with little force, might be hung on an axis passed nearly through its middle, instead of, as usual, by hinges at one edge. Cases have occurred where shipwrecked persons might have sent intelligence of their disaster to a distant coast, by a small vessel, or even a block of wood fitted up in this way. The method admits also of other applications, particularly in war.

As fluids act on surfaces, in a direction perpendicular to them, the water on the right side of a ship's bow is always pressing it towards the left side; but owing to the equivalent and contrary pressure there, the ship holds her course evenly between the two, or straight-forwards. When a ship, however, owing to a side wind, lies over or *heels*, as it is called, that side of the bow which sinks most is more pressed than the other; and were there not a counteracting inclination of the rudder then made, constituting what is called *weather-helm*, the ship's head would come round to the wind. Now ships so rarely have the wind exactly astern, that to diminish the almost constant necessity for *weather-helm*, the mast or masts, and consequently the mass of the sails, are placed more towards the bow than the stern.

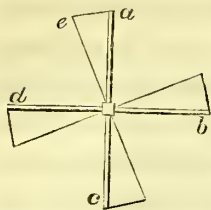
Again, because the bow of a ship is oblique

downwards as well as sideways, the water, when she moves, is constantly tending to lift the bow ; hence when a vessel is dragged by a low horizontal rope, as in the case of a boat attached to a sailing ship's stern, or is moved by paddle-wheels, like steam-boats, the bow rises much out of the water, and the stern sinks in the hollow or furrow of the track : but when she is driven by sails, as these are high on the mast, and are acting therefore on a long lever to depress the bow, the two opposing tendencies just balance each other, and the vessel sails evenly along.

The form of the fore part of a ship has less influence upon her speed of sailing, than the form of the hind part, called the *run*, from the middle to the stern. When a ship is at rest, there is of course as much forward pressure of water about the stern as of backward pressure on the bow ; but when she sails, she is running away from the propelling pressure, and is increasing the resisting pressure. A gradual tapering of the hind part, therefore, or a *fine run*, as it is called, which allows the water to apply itself readily to it, as it passes along, must influence much the rate of sailing. The fore part of any mass drawn through the water, however blunt or square, becomes in effect sharp or rounded by a quantity of water which it pushes on before it. A tree, or the tapering mast of a ship, can be drawn through the water more easily with the large end foremost, than in the contrary way.

The *common windmill* furnishes another illustration of the action of fluids on oblique surfaces.

The face of the windmill is turned directly to the wind, but the four flat vanes or sails, of which the great wheel consists, are individually oblique. Thus the edge *a* of the vane *a e*,



is more forward as regards the coming wind or a spectator in front, than the edge *e*, and the action of the wind, therefore, being perpendicular to the oblique surface *a e*, pushes it in a degree towards *a*. The same remark applies to each of the other vanes where the edges *b*, *c*, and *d* are in front, and those marked by the fainter lines are behind; so that each vane produces an equal effect in turning the wheel. The law of the “decomposition of forces,” explained at page 84, tells in what proportions the force of the wind is exerted to push the wheel backwards against its supports, and to turn it round.

Windmills were first used in Europe in the fourteenth century, and they are still of great importance in countries where there are no waterfalls, and little fuel for steam-engines. In some of the richest European landscapes, every height is crowned by its busy windmill, grinding corn, or sawing wood, or pressing oil-seeds; and over the plains, similar wheels are pumping water for domestic use, or incessantly draining the land.

The *smoke-jack* of our chimnies is a small windmill, driven by the ascending current of air in the chimney.

The *feathering of an arrow* acts in part on the principle of the windmill. The feathery projection



from the shaft is not quite straight, but winds round it a little, like the thread of a screw; and the arrow, therefore, constantly turns as it flies, and goes straight to its object although the shaft itself be bent, because any deviation is constantly correcting itself.

The rifle-barrel in fire-arms has spiral furrows or threads along its interior surface, so that the bullet in passing out receives a turning motion corresponding to that of an arrow, and producing similar results. A bullet which receives any other turning motion than round the line of its course,—and most bullets from a common barrel do acquire such, owing to the irregularity of their form, or unequal friction at the mouth of the piece,—is sure to deviate from its course, because unequally pressed or resisted by the atmosphere. A good rifle fixed to its place will send a succession of shots through the hole made in the target by the first shot, at the distance of 200 yards. Duels have been fought with rifles, and the parties having fired at the same moment, have been corpses the moment after.

It might be supposed that a wheel which the wind turned by *direct* action on the rim, as water turns common water-wheels, would be preferable to the windmill-wheel above described, which is turned by *oblique* action on the face: accordingly, a wheel like a water-wheel, only with broader vanes, has been placed in a house or cover, so that only one side at a time was exposed to the wind;—but it is a powerless machine. The oblique vaned wheel may apply to use only half or less of

the force of the air which reaches it, but its wide expanse receives a stream of air often of thirty feet in diameter, while an ordinary window would admit that required for a wheel of equal size of the other construction.

There are some situations where it would be an advantage to have water-wheels like the common windmill-wheel, *viz.* where the stream is sluggish, and is deep enough to allow a large wheel to be wholly immersed.

A small wheel of this sort, with broad oblique vanes, has been used as a means of ascertaining the rate of a ship's sailing. It is allowed to drag astern in the water; and the number of revolutions made in a given time marks the ship's speed.

A windmill-wheel made to turn during a calm by force applied to its axle, would be pressed endways, or in the direction of its axle, just as if wind were blowing upon it, owing to the re-action of the still air, through which its oblique vanes were made to sweep. Such a form of wheel fitted to work in water, and called a water-screw, has been applied at the bow or stern of steam-boats, to propel them in canals where there was no room for side wheels. But as from the obliquity of the surfaces only part of the applied power becomes propulsive—the remainder being wasted in the lateral strain or twisting of the water—the method is not applicable to general purposes.

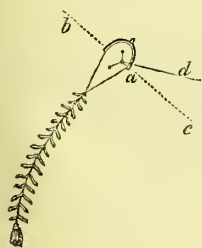
Two small windmill-wheels placed horizontally one above the other, on the same axis, and made to turn in opposite ways by springs or otherwise, would rise in the air, carrying a certain load with

them, and would constitute, therefore, a flying machine.

The effect of a single oar projecting from the stern, used to propel a boat or vessel, in the manner called *sculling*, is referable to the law now under consideration. The oar or scull rests on a round-headed prop or nail at the stern, and is made to vibrate from side to side. In all its positions it has the surface which presses the water turned obliquely backwards; hence the re-action of the water drives the boat forward.—In China, large vessels are moved by a single sculling oar, which half the ship's company may be urging at the same time. A sculling oar may be regarded as a single vane of such a propelling wheel or water-screw as above described, made to sweep across, behind the vessel, alternately to the right and to the left.

The action of a fish's tail, and of the bending of an eel or snake in water, partly resembles that of the sculling oar. Many people believe that the tail of the fish is only the rudder of the body, and that the fins give it forward motion—as is true of a bird's tail and wings,—but the fish's tail is in fact the great instrument of motion, while the fins serve chiefly to steady and direct the motion.

A *paper kite* rising in the air is another example belonging to this place. Its cord *d* is attached to it above the middle of its loop, and therefore so as to make it present always an oblique surface to the wind; and by the action of the wind, perpendicular



to its surface, it rises as if pushed up in the direction  $c a$ , or as if drawn up in the direction  $a b$ . A kite might be made large enough to lift a man. Cats have been sent up at kites' tails, and have fallen down safely under parachutes from the greatest elevations. It might be safer for a man to rise at a kite's tail to reconnoitre an enemy's position, or to survey an unknown country, than under a balloon, as was practised by the French during the revolutionary wars. He might have the security of a parachute, and the power of regulating the obliquity of attachment of the rope, so as to command his ascent or descent at pleasure. An exhibition was made in October 1827, between Bath and London, of a car drawn along the highway by kites. That they might ascend to a great elevation, where the wind is generally stronger than below, they were attached to each other in a row, so that the second kite mounted as if its cord were held by a hand at the first, the third as if rising from the second, and so forth. The projector of this novelty hoped that he had pointed out a most valuable means of travelling across extensive plains, sandy deserts, tracts of snow, &c., and in all cases, nearly with the speed of the wind.

*“ Fluids lifted in opposition to gravity.”* (See the Analysis.)

Water, as we have seen in former parts of this work, is to the living universe, in some degree, what the blood is to the animal body, and a constant supply and circulation are required. This supply has been provided for to an extraordinary

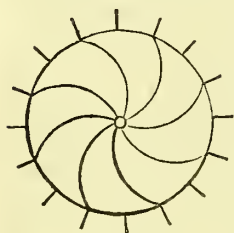


extent, by the operation of natural causes ; but for many purposes of human society water is still required where none naturally exists. A great variety of means have been employed for raising it, some of which, sufficient to illustrate the whole, are now to be considered.

Water may be raised in a bucket which is attached to a rope to be pulled up by the hand.—The rope carrying the bucket may be drawn up more easily by being wound round a barrel or axle turned by a winch.—There may be a succession of buckets on a rope, rising one after the other, and when emptied, descending again on the opposite side of the wheel or axle which lifts them : the rope to which they are attached being a circle or *endless rope*, and constituting with them what is called the *bucket-machine*.—Instead of buckets on such an endless rope or chain, there may be a succession of flat pieces of wood, which, on being drawn up through a large tube or barrel, like loose-fitting pistons, will raise a copious stream of water : this is the contrivance called the *chain-pump*.—Or simply an endless rope of hair, very rough, passing round one wheel above and another below, may be whirled quickly by turning the upper wheel, so that a mass of water adhering by friction to its rising half, shall be thrown into a reservoir at the top where it passes over the upper wheel : several such ropes may be joined side by side to increase the effect.—But the most important of all water-raising engines are the *lifting and forcing pumps*, already described at page 355. They are used to draw from wells, to drain mines,

to send a supply over cities, to pump ships, to throw water for extinguishing fires, and for many other purposes.

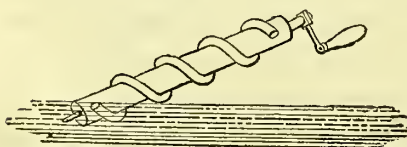
A stream of water passing through a garden, or in the midst of fields, may have beauty with little utility, unless it can be employed to irrigate the vegetable creation around. In the fields and gardens of Persia, where the heat of the sun is very intense, the streams are caused, by their own action, to lift a part of their water into elevated reservoirs, from which it again flows in sloping channels to wherever it is required. A large water-wheel is placed so that the stream may turn it, and around its circumference buckets are attached, to be filled as they sweep along below, and to be emptied into a reservoir as they pass above—or instead of buckets, the spokes of the wheel are themselves made hollow, and curved as



here represented, so that as their extremities dip into the water at each revolution, they receive a quantity of it, which runs along them as they rise, and is discharged into a reservoir at the centre. These are usually called

*Persian wheels*, but they are as commonly employed on the banks of the Nile and elsewhere, as in Persia.

A pipe wound like a screw upon a sloping barrel, and made to dip its lower mouth into water at each revolution



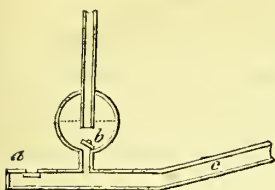
of the barrel, will also raise water : the lower portions of the turning pipe will always be full of it, and it will be rising in them to the top, as if on an inclined plane. Archimedes was the inventor of this beautiful water-screw, and his name has remained to it. It may be turned by hand, or by a passing stream which acts on the vanes of a water-wheel affixed upon it.

Water may be raised by producing centrifugal force at the upper end of a bent pipe which dips into a reservoir. Supposing the pipe to be bent as here represented, and the horizontal arm *a* to turn like the spoke of a wheel, round the upright portion as the axis,—if the pipe be once filled with water, and be turned with sufficient speed, it will continue to throw out a constant stream from the end *a*. To increase the discharge there may be several horizontal arms from one larger upright pipe, all emptying themselves into a circular trough or reservoir ; and to prevent the necessity of refilling the apparatus after every interruption of its motion, a valve opening upwards must be placed at the bottom. This contrivance has been called the *centrifugal pump*, because the water is raised at *b* as in a pump, by the pressure of the atmosphere, to supply the place of that which is thrown out from *a* by the centrifugal force. The velocity of rotation must bear proportion to the height of the discharging aperture *a*, above the surface of the water in the reservoir.

It had long been observed in household experience and elsewhere, that while water is running

through a pipe, if a cock at the extremity be suddenly shut, a shock and noise are produced there. The reason is, that the forward motion of the whole water contained in the pipe being instantly arrested, and the momentum of a liquid being as great as of a solid, the water strikes the cock with as much force as if it were a long bar of metal or a rod of wood having the same weight and velocity as the water. Then, as a fluid presses equally in all directions, a leaden pipe of great length, may be widened, or even burst in this experiment.—Lately this forward pressure of an arrested stream has been used as a force for raising water, and the arrangement of parts contrived to render it available has been called, on account of the shocks produced, the *water-ram*. The ram may be described as a sloping pipe in which the stream runs, having a valve at its lower end, to be shut at intervals to arrest the stream, and having a small tube rising from near that end towards a reservoir above, to receive a portion of the water at each interruption. Now water allowed to run for one second, in a pipe ten yards long, two inches wide, and sloping six feet, acquires momentum enough to drive about half a pint, on the shutting of the cock, into a tube leading to a reservoir forty feet high. Such an apparatus, therefore, with the valve shutting every second, raises about sixty half-pints or four gallons in a minute. The valve is so contrived that the stream works it as desired.—In this figure, which represents the lower end of the water-ram, *a* is the opening by which the stream escapes from it, and the valve or flap seen





below the opening is that which by suddenly shutting arrests the stream. The valve is made so heavy, that the stream must run for a certain time to acquire force enough to shut it; and in the instant of its shutting, a little of the advancing water passes upwards through the valve *b* towards the reservoir. The water in the main pipe then becoming stagnant again, no longer has power, by its weight alone, to keep the valve *a* shut: this, therefore, falls open and the stream begins again, again to be arrested as before; and as long as the supply of water lasts, the action of the apparatus continues. The action of a water-ram has been compared to the beating of an animal's pulse. The upright tube has usually a reservoir at the bottom, where it first receives the water, constituting there an air-vessel *b* (described at page 332), which, by the air's elasticity, converts the interrupted jets first received, into a nearly uniform current towards the reservoir. The supply of air to this vessel is maintained by the contrivance called a *snifting-valve*.

In the preceding examination of the doctrines of fluidity, we have had to touch on many of those phenomena of nature and art which are the most important to man; yet we have seen how beautifully simple and intelligible they are all rendered when referred, by a methodical arrangement, to a few heads dependent on the "fundamental truths." Each one of the many particulars belonging to

this department, and which when now explained appears so simple and obvious, has yet been a distinct step in the slow progress of discovery or invention, and probably when first made has filled some ingenious mind with intense and purest delight.

## PART III.

(CONTINUED.)

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 SECTION IV.—ACOUSTICS,  
OR PHENOMENA OF SOUND AND HEARING.
 

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## ANALYSIS OF THE SECTION.

1. *SOUND is heard when any sudden shock or impulse is given to the air, or to any other body which is in contact directly or indirectly with the ear.*
  2. *If such impulses be repeated at very short intervals, the ear cannot attend to them individually, but hears them as a CONTINUED SOUND, which is UNIFORM, or what is called a TONE, if the impulses be similar and at equal intervals, and is GRAVE or SHARP, according as they are few or many in a given time ; and all continued sound is but a repetition of impulses.*
  3. *When the number of impulses in a given time producing some uniform continued sound has a simple relation, as of half, third, fourth, &c., to the number producing some other such sound which is heard either simultaneously with it, or a little before or after, the ear is generally much and pleasingly affected by the circumstance ; and the sounds are said to have MUSICAL RELATION to each other, or to be ACCORDANT, while all others are termed DISCORDANT.*
  4. *The shock which causes the sensation of sound SPREADS or is propagated in all bodies, somewhat as a wave spreads in water, with decreasing strength as the distance increases, but with a velocity nearly uniform, and which in air is about 1,142 feet per second.*
  5. *Sound is REFLECTED from smooth surfaces, and hence arise many curious and pleasing effects called ECHOES, &c.*
  6. *The structure of the ear illustrates the laws of sound.*
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EARLY inquirers into nature had remarked that in most instances of noise or sound there was pre-

sent a shock or trembling of the sounding body, often visible, but sometimes only sensible to the touch, or discoverable by other means; it was noted, for instance, in the string of a harp, in the reed of a hautboy, in the prongs of a tuning-fork, in the lip of a bell: but it was reserved for the moderns to understand fully, that the animal organ called the ear, is merely a structure of parts admirably adapted to be affected by the concussions or tremblings of things around; and that sounds in all their varieties are merely such motions, affecting the ear through the medium of the air which surrounds it, or of some other body, or series of bodies, reaching from the trembling thing to the ear.

The delicacy and complexity of an organ destined to feel and to distinguish such slight and varying influences, and the vast importance of it to man, as that which makes him capable of using language, besides being his ever-watchful monitor of surrounding occurrences, and the channel by which the fascination of music enters, render this subject, to all who love to read in nature the attributes of its author, a most favourite study.

Because all the bodies around us are immersed, in common with ourselves, in the ocean of air which covers the earth, we are much more frequently warned of the shocks and tremblings of which we have been speaking, by their effect on the air, than in any other way; hence the early prejudice that air was necessary to sound, and hence, in part, the reason why the doctrines of sound have generally been accounted a part of



pneumatics. We shall now find, however, that all bodies are more or less fitted to convey these tremblings, and that air in many cases is neither the quickest nor the best conductor. Although our notions on the subject are thus corrected, it is still convenient to study the theory of sound as a part of *Pneumatics*.

1. "*Sound is heard when any sudden shock or impulse occurs in a body having communication, through the air or otherwise, with the ear.*" (Read the Analysis.)

Common instances of a single impulse are—the blow of a hammer—the clap of hands—the crack of a whip—a pistol-shot—any explosion—the thunder-clap.

The loudness of sound conveyed by air depends on the air's density. A bell enclosed in the receiver of an air-pump is heard less and less distinctly as the air is exhausted, and in a vacuum is not heard at all.—Even the blow of a hammer, in a vacuum, is not heard if care is taken to prevent the shock from being communicated through neighbouring solid bodies.—In the thin air surrounding a lofty mountain-top the report of a pistol is much less loud, and human voices are weaker.—In the condensed atmosphere of a diving-bell a whisper is loud.—When volcanoes and various other resemblances to the constitution of our earth were first discovered in the moon, some persons fancied that during the stillness of night we should hear the thunder there :—but supposing the thunder to happen, and to be ever so loud, it

could not be heard on earth, because there is no medium to bear thither the pulses of sound—there is a vacuum between.

2. *Impulses quickly repeated cannot be individually attended to by the ear, and hence they appear as one continued sound, of which the pitch or tone depends on the number occurring in a given time ; and all continued sound is but a repetition of impulses.* (Read the Analysis.)

If a wheel with teeth be made to turn and to strike any elastic plate, as a piece of quill, with every tooth, it will, when moved slowly, allow every tooth to be seen and every blow to be separately heard ; but with increasing velocity the eye will lose sight of the individual teeth, and the ear, ceasing to perceive the separate blows, will at last hear only a smooth continued sound, called a *tone*, of which the character will change with the velocity of the wheel.

In like manner the vibrations of a long harp-string, while it is very slack, are separately visible, and the pulses produced by it in the air are separately audible ; but as it is gradually tightened, its vibrations quicken, so that, where it is moving, the eye soon sees only a broad shadowy bellying line ; and the distinct sounds which the ear lately perceived, seeming now to run together on account of the shortness of the intervals, are felt as one uniform continued tone, which constitutes the note or sound then belonging to the string.

Again, if a current of air passing through a tube or opening, be in any way interrupted at regular

and very short intervals, as by a little stop-cock placed in the opening, of which cock the plug, instead of being only partially turned by a cross-handle, as in a common beer-cock, has a wheel fixed upon it, so that any desired rapidity of rotation may be given to it,—then at every time when the passage for air becomes open, there will be a certain shock given to the air around, and the repetition of such shocks will constitute a musical tone. This apparatus can produce all tones, and it enables us with great precision to ascertain the number of pulses required to constitute any given tone.

It is the elasticity of any string used to produce a tone which causes the repetition of the percussions, and therefore the continuance of the sound, thus :—the string having been pulled at its middle to one side, and then let go, is, owing to its elasticity, carried back quickly to the straight position; but by the time that it has reached this, it has acquired a momentum which, like the momentum of a vibrating pendulum, carries it nearly as far beyond the middle station, as the distance from whence it came :—it has to return therefore, by its elasticity, from this second deviation, in the same way; but still passing the middle as before, it has again to return; and thus continues vibrating uniformly as a pendulum does, until the resistance of the air and friction gradually bring it to rest. A large vibration of any string, like a large oscillation of a pendulum, occupies very nearly the same time as a smaller, because the farther that the string is displaced or bent, the more forcibly,

and therefore quickly, is it pulled back again by its elasticity : hence the uniformity of the tone produced by a musical string is not injured by the different force with which the finger of the player may touch the string. According, however, as the vibrations of a string are more extensive or quicker, the impulses given to the air are more sharp or forcible, and hence the sound becomes louder. And this explains why sharp sounds are generally also loud. Vibrations which are comparatively few and slow, strike the ear very gently, as in the flapping of a pigeon's wing, or in the play of a switch.

The most familiar instance of sounding vibration is that of an elastic cord extended between two fixed points, as in stringed instruments of music : but because elastic bodies generally, when by any force their natural form is for a time altered, recover it when allowed, not by a first effort, but like the string of a pendulum, after a series of oscillations, almost all such bodies repeat many times an impulse once given to them, and thus may become the means of producing a continued sound.—If a solid rod of steel, glass, or any other elastic substance, be fixed firmly at one end and left free at the other, and if that other be then pulled a little to one side of its station of rest, and suddenly let go, it will immediately seek its station again, but by the momentum acquired in the approach, will go beyond it : it will then return as before, but again to pass, and so will continue to vibrate with diminishing force for a considerable time.—A boy at school, thus, sticks the



point of his penknife into the bench, and by one touch makes it produce a continued uniform sound of considerable duration.—The prongs of a tuning-fork, or of the common sugar tongs, vibrate and sound in the same way.—In the musical snuff-boxes and chimney-clocks, the sounds are produced by the vibration of little rods of steel, fixed by one end, in a row, like the teeth of a comb, and touched by small pins or points projecting from a turning barrel.—Any elastic flap, as of metal or of tough wood, placed over an opening, so as to stand away from it a little when not pressed by passing air, but to close the opening if so pressed, becomes a sounding reed when air is gently forced through the opening:—thus, the air first pressing on the flap to close it, causes a momentary interruption of the current, but the flap immediately recoiling from the blow, as well as by reason of its own elasticity, again opens the passage, and the continued rapid alternation of the shutting and opening produces the tone.—The reed of a clarionet is a thin plate of elastic wood, made to vibrate in this way.—The drone of the bag-pipe and the common straw-pipe, are reeds of nearly the same kind.—The Chinese organ, and the sweet instrument lately introduced under the name of *Æolina*, have reeds which differ from these, by beating *through* the opening instead of merely *on* its face.—Elastic rods simply resting on supports at both ends, or suspended by their middle, will also vibrate: a musical instrument is thus made of pieces of glass laid upon two strings, and struck by a cork hammer: in the island of

Java, a rude instrument of the same kind is made of blocks of hard elastic wood.—A portion of a hollow sphere of elastic metal very readily takes on a vibration, during which its form is constantly changing from the perfect round to the oval, and conversely; there is consequently repeated percussion of the air, and a continued sound, and the thing is called a *bell*. A bell admits of great variety of shape, and may be made of any elastic substance, as metal, glass, earthenware (buyers ring earthenware to ascertain its soundness), and even of hard wood.—The *Chinese gong* is a metallic vessel shaped like a common sieve, having a manner of vibration very peculiar, and producing sounds that are rousing and sublime.—The *drum* has a tense elastic membrane on which the blows of the drum-stick are received: its tone ceases quickly, because the motion of so broad a surface is much resisted by the air.—In the flute, flageolet, common organ-pipes, &c. the air is forced through narrow passages, and is divided by sharp edges, in such a way as to suffer repeated but perfectly regular condensations or interruptions sufficient to affect the ear; and hence the endless variety of sweet continued sounds which these contrivances are known to produce.

To the production of a tone, it is of no consequence in what way the pulses of the air are caused, provided they follow with sufficient regularity: witness, in addition to some of the instances given above, the pure sound produced by the motion of a fly's wing—supposed by many to be the voice of the insect. The clacking of a corn-mill,

and the noise of a stick pulled along a grating, are not tones, only because the pulses follow too slowly.

Where a continued sound is produced by impulses which do not, like those of an elastic body, follow in regular succession, the effect ceases to be a clear uniform sound or tone, and is called a *noise*.—Such is the sound of a saw or grindstone—the roar of waves breaking on a rocky shore, or of a violent wind in a forest—the roar and crackling of houses or of a wood in flames—the mixed voices of a talking multitude—the diversified sounds of a great city, including the rattling of wheels, the clanking of hammers, the voices of street-criers, the noises of manufactories, &c. : which rough elements, however, at last mingle so completely that the combined result has often been called “the hum of men,” from analogy to the smooth mingling miniature sounds which constitute the hum of a bee-hive.

“*Grave and sharp sounds.*” (Read the Analysis.)

The difference of sounds, which depends on the different number of vibrations of the sounding body in a given time, divides them into those called *bass*, *low*, or *grave* notes, for comparatively few and slow vibrations ; and those called *high*, *shrill*, or *sharp*, for vibrations more numerous and quick.

The frequency of vibrations in strings increases with their *shortness*, *lightness*, and *tension*—for if a string be *long* or *heavy*, there is a greater mass of matter to be moved, and hence a slower

motion ; and if a string be slack, the force of elasticity which pulls it from any deviation back to the straight line, is so much the less. It is found that a string taken of half the length, or of one-fourth the weight, or of quadruple the tension of another string, vibrates twice as fast on any one of these accounts.

These truths are familiarly illustrated in the violin. The low or bass string is thick and very heavy from being covered with metallic wire, and the others gradually diminish in magnitude and weight, up to the smallest or treble. The strings are tuned to each other by being attached by one end to moveable pins, which, when turned, increase or diminish their tension ; and the sound produced by each may be afterwards varied to a certain extent, by the performer pressing different parts of it with the finger against the board, so as to shorten the vibrating portion.

An analagous law, as to the influence upon tone, of weight and dimensions, holds with respect to bells, glasses, reeds, &c., and enables us to use these also in the construction of musical instruments.

3. “ *When the number of impulses producing some continued sound has a simple relation, as of half, third, fourth, &c. to the number producing some other sound which is heard either simultaneously, or a little before or after it, the ear is much and pleasantly affected ; and the sounds are said to have musical relation to each other, or to be accordant, while all others are termed discordant.*” (Read the Analysis.)



Understanding now that all continued uniform sounds are produced by a repetition of similar beats or vibrations, we perceive that in the series from grave to sharp, there must be such as, with respect to the number of beats in a given time, are related to each other as the numbers 1, 2, 3, 4, &c., or, which is the same thing, as 10, 20, 30, &c. Now as between two sounds, one of which has 20 beats while another has 10, there will be a coincidence at every second beat of the quicker, and between sounds whose beats are to each other as 30 to 20, there must be a coincidence at every third beat of the quicker, and so forth,—we should naturally expect the ear to be differently affected by such correspondence, than when the coincidence is either less frequent, or is irregular. Accordingly we find that all sounds which have such simple relations to each other, are remarkably agreeable to the ear, either when heard together, or in close succession; while those in which the coincident beats are farther apart, are heard with indifference, or are felt to be positively harsh and disagreeable. It is a fact offering itself to be noticed here, that the coincident or double pulses of any two concordant sounds become the cause or elements of a third sound, perfectly distinct from them, but which is always heard with them, and is called their *grave harmonic*, or *resultant*: it is the same as a simple sound having as many vibrations in a given time, as there are coinciding beats between the two other sounds.

If a long musical string be made to sound, and the number of its vibrations in a given time be

ascertained, we find that if only half of it be allowed to vibrate at a time, as when a finger presses its middle against a board, that half will vibrate twice as fast; and similarly, a third part, three times as fast; a fourth part, four times as fast; and so on, producing the sounds or tones most nearly related to each other. A fine illustration of this is afforded by the string of a violoncello, when made to vibrate by a bow moved very gently across it, near the bridge; for it often divides itself spontaneously into two, three, or four, &c. equal vibrating parts or bellies, with points of rest between them called knots: when this happens, there are heard not only the sound or note belonging to the whole length of the string, but also, more feebly, the subordinate notes belonging to its half, third, or fourth, &c., according to circumstances, beautifully mingling with the first sound, and forming with it a rich harmony. Often in such a case the subordinate sounds swell with such force as to overpower for a time the fundamental note; but any one such sound is rarely of long duration. The same harmonic sounds may be produced still more certainly, while drawing the bow across the string, by touching the string lightly with the finger, at one of the points where we wish it to divide. Even a tune may so be played.

The sounds thus belonging to a single cord or string, and produced by its spontaneous division into different numbers of equal parts, constitute, when heard together or in succession, what may be called the simple music of nature herself. It

is produced pleasingly, as just described, by the single string of a violoncello ; but in the most perfect manner by the instrument called the Æolian harp.

The Æolian harp is a long box or case of light wood, with harp or violin strings extended on its face. These are generally tuned in perfect *unison* with each other, or to *the same pitch*, as it is expressed, except one serving as a bass, which is thicker than the others, and vibrates only half as fast ; but when the harp is suspended among trees, or in any situation where the fluctuating breeze may reach it, each string, according to the manner in which it receives the blast, sounds either entire, or breaks into some of the simple divisions above described ; the result of which is the production of the most pleasing combination and succession of sounds that ear has ever listened to, or fancy perhaps conceived. After a pause this fairy harp may be heard beginning with a low and solemn note, like the bass of distant music in the sky : the sound then swells as if approaching, and other tones break forth, mingling with the first, and with each other : in the combined and varying strain, sometimes one clear note predominates and sometimes another, as if single musicians alternately led the band : and the concert often seems to approach and again to recede, until with the unequal breeze it dies away, and all is hushed again.—It is no wonder that the ancients, who understood not the nature of air, nor consequently even of simple sound, should have deemed the music of the Æolian harp supernatural, and,

in their warm imaginations, should have supposed that it was the strain of invisible beings from above, come down in the stillness of evening or night to commune with men in a heavenly language of soul intelligible to both. But, even now that we understand it well, there are few persons so insensible to what is delicate and beautiful in nature, as to listen to this wild music without emotion ; while the informed ear finds it additionally delightful, as affording an admirable illustration of those laws of sound which human ingenuity at last has traced.

As the simple scale of sound, called a *chord*, which nature thus gives by the spontaneous dividing of a single string, has considerable vacancies in it, human taste or feeling, long before there was any theory of music, had joined to it the notes of two additional strings, one sharper or more acute than it, and the other more grave ; of which additional notes, while part agreed, or were in unison with certain notes of the principal chord, the remainder just served to fill up its larger intervals, and to complete a scale of nearly uniform interval—as three ladders having unequal intervals between their steps, might still, if placed together complete a stair of easy ascent. The relation between these strings or chords is such, that the principal beats thrice for twice of the low chord, and the high chord beats thrice for twice of the principal :—and in the complete scale of notes, the principal is five notes above the lower and five notes below the higher. So truly natural is the scale thus formed, that it has arisen in all nations,



however remote or unconnected ; and an untutored individual, in attempting to raise his voice by regular steps, falls into it almost as readily as the learned professor. The scale has eight steps or notes between any tone, and the tone above it vibrating twice as fast, or the tone below it vibrating half as fast ; these two tones or notes being hence called the *octaves* above and below the *note* with which they are compared, and the intermediate notes which fill up either octave from the fundamental note are distinguished by the names of *second*, *third*, *fourth*, &c. in ascending or descending. The numbers which express the relations of beats among the notes of an octave are easily found, from our knowing the relative number of beats in the notes of any one simple chord, and the relation as above described of the three chords forming the compound scale. The following table exhibits these numbers or the arithmetical expression for the notes of an octave, as well as the corresponding lengths of a given string required to produce them, and the English designation of the notes by letters, and the continental designation by names, these names being the first syllables of certain verses sung by learners.

Number of vibrations .....	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Length of string ...	1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$
English characters...	C	D	E	F	G	A	B	C
Continental names...	ut	re	mi	fa	sol	la	si	ut

The musical scale, however far extended, is a repetition of similar octaves, so that any note in

it vibrates just twice as often as the corresponding note in the octave below, and half as often as that in the octave above. The lowest note which is perceptible to the human ear has about thirty beats in a second, and the highest, about thirty thousand; and there is included between these two, a range of nearly ten octaves. To certain ears the extremes of this range are totally inaudible, as if their power did not reach so far. Some persons do not hear at all the sharp note of the grasshopper, while some are equally insensible to the lowest tones of an organ or piano; and yet to all, the perception of intermediate sounds may be equally perfect. Few musical instruments comprehend more than six octaves, and the human voice in general has only from one to three, the female voice being in pitch an octave higher than the male.

If the intervals in the musical scale were all equal, a performer might choose indifferently any note as a fundamental or key note, and would only have to attend to the number of intervals above and below it; but, in fact, the relation of the three constituent chords is such, that the third and seventh intervals in ascending from a key-note are only about half as large as the others. It is owing to this circumstance that in *changing the key* on any instrument, certain notes belonging to other keys are half a note too low or too high, that is, too *flat* or too *sharp*, and must be changed accordingly. And hence, when an instrument is to be used to play in all keys, its larger intervals must be divided into two parts. The fact of these

unequal intervals, ill understood, is what gives an appearance of great complexity and difficulty to musical science.

*Melody*, in music, is when notes, having the simple numerical relations of beat which we have been describing, are played in succession : *harmony* is when two or more such notes are sounded together. The effect of both is delightfully increased by what is called *measure*, viz. making the duration of the notes or strain correspond with certain regular divisions of *time*. This gives to the ear a prescience, to a certain degree, of what is coming, with the pleasure of having expectation realized, as happens similarly from the metre and rhyme of poetry : it moreover enables the memory to retain musical combinations of sound—for the airs of the Æolian harp, which observe no *time*, cannot be learned or repeated. The music of a single drum is that of *time* only.

*Melody, harmony, time, and varying intensity of sound*, are the four constituents of music, and it seems that almost every state of mind has, in some combination of these, an appropriate expression, intelligible to the general feeling of the human race. The exact relation between the movements of the animal spirits, as it has been expressed, or the fluctuating stream of feeling, and the varying flow of sound in a musical composition, is not clearly understood, but the fact of their correspondence and its consequences are most remarkable. Under many circumstances, the association between the feeling and the expression is so strong, that the latter is often spontaneously betraying

itself;—witness the almost constant humming, or low song, of some contented beings—the singing and whistling of careless childhood, or of the light-hearted rustic living among the beauties of nature—the heart-rousing strain of the hunter or warrior—and the tender expression of many of the modifications of anxiety and sorrow. The musical sensibilities are by no means limited to the human race, for there is no expression more exquisite than in the song of the nightingale during the evenings of spring, or of the thrush and blackbird, in the same season, amid the quiet retreats of our woodlands,—the music of which untutored songsters is made up of the same elements as our own.

The *accompaniment* of an air afforded to a singer by one or more instruments, and which is so pleasing, is chiefly the sounding simultaneously, in a subdued manner, some other notes of the chords to which the several vocal notes belong. *Duetts* and more complicated *concert-pieces* have their origin from the same source: and highly cultivated musical sense can even follow and enjoy several melodies played together.

Musical notes, by whatever instrument produced, have to each other the same numerical relations in the beats or vibrations which constitute them. The different qualities of tone, therefore, from different instruments, can only depend on the peculiarities of the single beats, as to whether they are sharp or soft, strong or weak, &c. Such is the extraordinary nicety of perception which the human ear possesses in this respect, that it can not



only distinguish different kinds of instruments, as a flute and clarionet, playing the same note, but different instruments of the same kind, even to the extent, for instance, of recognizing each one of a hundred voices singing the same air. One of the greatest charms of concert-music, is that the voice and the different instruments may take up separately, parts of the strain suited to their individual expression—the flute and clarionet, for instance, breathe softness; the trumpet and drum arouse; the harp rolls forth its brilliant chords; the violin leads the flowing sound through rapid and endless variety; and so of the rest.

That there might be correspondence in instruments when played together, and a known pitch when played apart, it became necessary to fix on some tone or number of vibrations as a point of comparison. Hence *tuning-forks* have been made of steel, with length of prongs calculated to produce a certain note. This note is usually the fourth A or *la*, from the bass of the piano-forte, and vibrates about 430 times in the second;—and when the note of the same name on any instrument is *tuned* in unison with this, the other notes can be easily adjusted according to the harmonic relations above explained.

Almost every substance or contrivance that can produce an uniform continued sound may enter into the composition of a musical instrument: hence the almost endless variety which the world has seen. The chief classes of instruments are *stringed instruments*, *wind instruments*, and *bells or rods*.

Of the *stringed instruments*, we may mention the *harp*, the *lyre* or *lute*, the *guitar*, the *viol* of all sizes, and the *piano-forte*. The harp, lyre, and lute, were the inventions of antiquity, and have brought down with them to the present times a thousand delightful associations. They awakened to inspiration the bards and poets of the young world, and they were the beloved companions of many of the noblest spirits of succeeding times. Their great charm appears to have been in their power to heighten the emotions produced by music's twin sister, poetry; and the combined effects seem to have been magical.—The other instruments mentioned are of comparatively modern invention, particularly the piano-forte; and their perfection has assisted in carrying the combinations of musical sound to degrees of complexity and difficulty of which antiquity dreamt not. It is a question, however, whether the style of much of the music now in vogue do not prove rather a degeneracy, than a desirable refinement of musical taste. Music is a language of nature, intelligible at once to all susceptible minds, and, in a degree, even to inferior animals; but modern art is attempting to make of it an artificial and conventional language, in which there may be fashion and change. The ornaments and accompaniments are now often so overwhelming, that the *melody*, in which the idea and sentiment really reside, is masked and almost lost; and an unpractised ear, particularly if listening to an *organ*, often discovers only an unmeaning succession of chords. And when a singer, abandoning the natural sim-

plicity of melody, strains to execute with the voice the complicated movements which belong properly to instrumental accompaniments, the attempt destroys the poetry, by either rendering the words inaudible, or by sacrificing their natural expression to some supposed appropriate expression of the ornamental music. These considerations may account in part for the insensibility of so many highly endowed persons to *what is now called* excellent music. Some of the tricks on the voice and on instruments, at present so common, are, to natural or graceful music, what tumbling and rope-dancing are to natural or graceful gesture. And when we hear noted professors avow their inability to sing a simple ballad, or to play an unadorned melody, must we not conclude that the natural sense of music has left them, as the relish for simple but the most invigorating fare has left the morbid epicure?

The *guitar*, as affording an accompaniment to vocal music, has many advantages. It is not too loud, yet the strains are very distinct: it admits of most touching expression; it is very easily learned by any one who should attempt to learn music; it is portable and cheap. The great facility of accompaniment on it depends on this, that the player is able by one position of the hand to touch the strings so that the sounds of all the six shall belong to the same chord:—three positions of the hand, therefore, for one key, produce all the notes and chords which a simple accompaniment requires; and the hand soon falls into these so readily, that the player is hardly sensible of exerting volition.

Among *wind instruments* are, the *flute*, the *flageolet*, the *organ*, the *clarionet*, the *hautboy*, the *horn*, the *trumpet*, &c. The pitch or tone of a tubular wind instrument, just as of a musical string, has relation to its length; and the vibrations causing the sound seem to be waves or condensations of air passing from the mouth to the extremity of the tube; being more frequent, therefore, as the tube is shorter:—when the bottom of the tube is closed, the wave has to come back again, and thus renders the note twice as grave. It appears also, that on blowing more strongly, the air in the tube divides into separate vibrating portions, as a string may divide to produce its harmonic sounds, and produces thus all the harmonic sounds belonging to the fundamental note of the tube. By blowing into a common German flute, for instance, it is possible to produce five ascending harmonics without moving the fingers at all. The music of a trumpet is limited to these five notes of the same chord; but in the flute, and other instruments with holes, the effective length of the tube is calculated from the upper end to the nearest hole left open; and each length has its harmonics.—If a tuning-fork, Jew's-harp, or any such sounding body, be held at the open end of a tube or other empty space, of dimensions calculated to produce a frequency of undulation in its contained air according with the pulses of the sounding body, then the tube or space will immediately give out its own beautiful tone: and if the space be enlarged or diminished in a double, triple, or any other simple proportion,—as a tube may be, by a piston moved



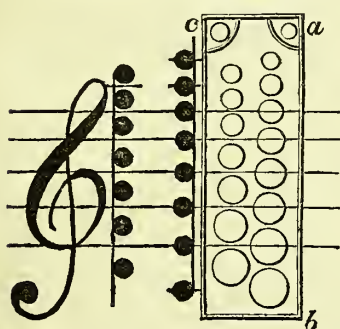
up or down in it, then will its note become the fifth, octave, twelfth, &c. above or below the original tone, although that tone continues unchanged. The tones of the Jew's-harp are well known to depend altogether on the varying dimensions of the player's mouth; but to obtain perfect music from it, three harps at least, to be substituted one for the other during the performance, are required to produce the notes of the three constituent chords of the common musical scale.—In wind-instruments with reeds, the tone depends on the stiffness, weight, length, &c. of the vibrating plate or tongue of the reed, as well as on the dimensions of the tube or space with which it may be connected. This truth is well illustrated in that instrument, the *Æolina*, already mentioned, which in improved and varied forms promises to become common, and one of the most expressive of wind instruments.—The sounds of the human voice are the sweetest of all, and are produced by the vibrations of two delicate membranes situated at the top of the windpipe, with a slit or opening, called the *glottis*, left between them, for the passage of the air. The tones of the voice are grave or acute, according to the varying tension of these membranes, and to the size of the opening.—In the *organ* there is a pipe for each note, and wind is admitted from the bellows to the pipes, by the action of keys, like the keys of a piano-forte. The organ may be played also very perfectly by a barrel, made to turn slowly under the keys, and to lift them in passing, by pins projecting from it at the required situations. Very complicated pieces

of music are thus set on barrels, but at great cost of study and labour, and therefore of money: now a plain barrel, made to turn near the keys of an organ during performance on it by the hands, might be made to record with mathematical accuracy every touch of the most finished player, by receiving marks of some kind from the keys as they were lifted; and to repeat with absolute accuracy, therefore, any performance, however delicate and exquisite, it would only be farther necessary to drive pins into the barrel where the marks remained, and afterwards to make these pins lift the keys.

*Bells* are often conjoined in sets, having the musical relations, and to some persons their music is very agreeable. There is in the tolling of a single bell a loudness and solemnity rendering it a fit accompaniment of funereal rites.

The *Chinese gong* partakes of the nature both of the bell and of a great drum, and has something in its sound which is singularly affecting. In its own country it bears a part in one of the most imposing ceremonies which man has ever imagined. On certain festivals, as the sun is sinking in the west, the whole population of China, a host of more than a hundred millions—issues forth under the single canopy of heaven, to testify, amid the thunder of gongs and the continued discharge of fireworks, that adoration and gratitude towards the Deity, which human nature, in all ages and climes, has felt to be due, and has eagerly sought to express, however blind as to the sublime simplicity of religious truth.

*Bells* or *goblets* of glass sound still more perfectly than those of metal, and by gentle friction on their edges with a bow or the wetted finger, their tones may be continued for any length of time, and may be made to swell and diminish like the human voice or the notes of a violin. A set of glasses, therefore, attuned to each other, according to the harmonic scale, becomes, for certain species of music, the most perfect of all instruments. It is in fact an *Æolian harp* at command. Dr. Franklin, who first constructed a set, doubled the long line of glasses upon itself, and placed the half-notes as outside rows. The author of this work, however, during some experiments on sound, found the *zig-zag* arrangement here represented to possess



certain advantages. The small open circles represent the mouths of the glasses standing in a box *a b c*, and the relation of the glasses to the written musical notes is shewn by the common music lines and spaces

which connect them. The learner discovers immediately that one row of the glasses produces the notes written *upon* the lines, and the other row the notes written *between* the lines; and he is mentally master of the instrument by simple inspection. This arrangement also renders the performance easy, for the notes most commonly sounded in succession are contiguous; and the relations of the notes forming a tune are so obvious to the

eye, that the theory of musical combination and accompaniment is learned at the same time. The set of glasses here represented has two octaves, and with the additional *flat seventh* and *fourteenth*, seen at *a* and *c*, which, when required, may be substituted for the corresponding glasses in the rows, it is capable of playing the greater part of our simple melodies. All the half-notes, if desired, may be placed in outside rows. The player stands at the side of the box between *a* and *b*, and has the notes ascending towards the right hand, as in a *piano-forte*.

#### *Musical ear.*

Philosophers have not yet been able to account for a remarkable difference among individuals, as regards their perception of the musical relations of sounds. Many persons, without understanding any thing of acoustics, or having studied music as a science, can tell instantly whether various notes heard together or in succession, have the mutual relations which we call musical—and which we now know to depend on the comparative numbers of beats in a given time; and they quickly recognise and learn to repeat tunes, and to sing a fit second or bass to the performance of another;—while there are persons, again, with an equally perfect sense of hearing, who can neither know if an air be played in tune, nor what air it is, nor can they ever sing alone or accompany. The former class of persons are said to have a *musical ear*, and the latter to want it; and although cultivation will raise mediocrity to considerable ex-



pertness, it cannot bestow the faculty where originally deficient. On this subject there is a very common misconception, which becomes a source of great mortification on one side, and of arrogance on the other, *viz.* that the possession of a musical ear, or the power of distinguishing notes, is the indication of all the finer qualities of the mind, while the want of it proves an opposite deficiency; and Shakspeare's opinion of him "that hath no music in himself," is often triumphantly cited as applicable to all who want the distinguishing ear. The truth, however, is, that many who possess this characteristic in a remarkable degree, are deficient in almost all else that humanity reveres,—witness the weak minds and disorderly lives of so many professed musicians,—while many, again, who have it not, are otherwise examples of excellence, and exquisitely sensible to other beauties and harmonies of nature. They may not be deaf, for instance, to the general music of spring, when all nature bursts forth in voice of rejoicing, nor to the awful music of the storm—they may feel as touching music the silence of a lone wood, contrasted with the unceasing din of multitudes—or even the stillness of night in a great city, where the astronomer, contemplating the wondrous spheres above, hears only the tongues of passing time in the church-towers, or the call of watchmen, faintly sounding in the distance. In fine, many distinguished poets and philosophers have had no musical ear.—That the charm of music is often as much from early associations as from peculiar aptitude in the individuals, is proved by the

effects so well known of the Swiss airs, when heard by native Swiss in foreign lands ; and, indeed, of the national melodies of all countries, whose people are happy, and mix song with their usual occupations,—it not being in nature, that at any period of life, or in any clime, a man should cease to deem those modulations lovely, which recall the ecstatic emotions of his infancy and childhood ; modulations learned in general from a parent's voice, perhaps an excellent mother's, whose affection was so long around him as a shield, whose tears fell to chide his errors, and to reward where there was promise of virtue ; whose steady judgment was his guide, whose faultless life was his example, and who in all things to him was a personification of God's goodness on earth.

It is the prejudice of which we are now speaking with respect to musical ear and musical taste, that, in the present day, condemns many young women, possessed of every species of loveliness and talent except that of *note-distinguishing*, to waste years of precious time in an attempt to acquire this talent in spite of nature ; but, when they have succeeded as far as they can, they have only the merit of being machines, upon which tunes are set as upon a barrel-organ, and of which the performance is often far from being pleasing to good judges. Such persons, when liberty comes to them with age or marriage, generally abandon the offensive occupation ; but tyrant fashion will force their daughters to run the same course. The waste of time now spoken of, is only one of many evil consequences which arise from the pre-

vailing false notions with respect to music ; a subject which, however interesting, cannot be farther pursued in this place.

“ *The trembling which causes the sensation of sound spreads in all bodies, solid or fluid.*” (Read the Analysis.)

As air consists of material particles held far apart from each other by the repulsion of heat among them, we can conceive how an impulse given to a certain portion of the particles is transmitted to those beyond, by the increase of repulsion as they approximate ; and from the second layer in the same manner to a third, and so on. And as in fluids the particles all mutually rest against, or repel each other, we can conceive why a motion produced in any part of a mass should be felt in every direction. The explosion of gunpowder, in which there is a sudden formation of a quantity of air, gives a shock all round which spreads as a spherical wave to a great distance.

Although material particles in the form of liquid or solid are so much nearer to each other than in the form of air, we still have many proofs, as stated at page 38, that they are not in absolute contact, and we therefore see the reason why the impulses producing sound should be transmitted through a liquid or solid in the same manner as through air, and even, by reason of the greater proximity of the particles, more quickly and forcibly than in air.

Instances of air carrying sound were given at page 499.—As further examples, we may cite the cases of what are called *sympathetic sounds*. Every

elastic body being sonorous, that is so say, being fitted to tremble when struck, with a certain frequency of oscillation, depending on its weight and shape, &c., if the air around it be made to tremble by any cause, with the velocity which it is fitted to take on or produce, it immediately begins to tremble in unison with the air ; and its motion or sound may continue after the original cause has ceased.—Thus almost any sound produced near a piano-forte whose dampers are raised, finds a responsive string, and if bits of paper are strewed upon the strings generally, those falling on the strings which return unisons or octaves to the sounding body are soon shaken off, while the others remain. A harp or guitar in a room with talking company, is often mingling a note with their conversation.—A wine glass or goblet may be made to tremble, and if on a table at all inclined, even to fall, by a person sounding on a violoncello near it, the note accordant to its own.

Sounding bodies vibrate much more quickly, or have sharper tones, if placed in light hydrogen, than in common air ; and more quickly in common air, than in any of the heavier gases :—because the lighter the surrounding fluid, the less is the resistance to a body moving in it. Thus also a bell will ring under water, but with a much graver sound than in the air.

That water is a vehicle of sound, is proved, by the fact last mentioned,—by the distinctness with which the blows of workers around a diving-bell are heard above,—by the fact that fishes hear very acutely, &c.



And the following are instances of sound conveyed by solids.—A scratch of a pin at one end of a wooden log is distinctly heard by a person applying his ear at the other end, although through the air it is not at all audible, even to the person who makes it.—Savages often discover the proximity of enemies, or of prey, by applying an ear to the ground and hearing the tread.—The approach of horsemen at night is easily discovered in the same way.—The report of a cannon placed on ice is carried much farther by the ice, than by the air around.—In the military operation of mining, or cutting a way under ground for the purpose of entering a citadel or blowing up fortifications, the approach of the enemy is often discovered by the subterranean sound of the pioneer's tools.—The awful muttering of earthquakes is merely the sound of subterranean explosions, conveyed from amazing distances, by the solid earth.

A superstitious man sleeping in the upper story of a lofty house had for some time heard, during the stillness of the nights, a singular beating noise near the head of his bed. There was no adjoining house beyond the wall, nor was there anything going on near him in his own house to account for it, and he at last deemed it supernatural. Accident at last discovered that in a hovel built at the bottom and outside of the wall against which his bed stood, there was a wooden clock hanging, of which the sound, while all else was still, became audible aloft.

It is easy to ascertain whether a kettle boils, by putting one end of a stick or poker on the lid, and

the other end to the ear ; the bubbling of the water then appears as loud as the rattling of a carriage in the street.—A slight blow given to a steel poker or common triangle, of which an end is held to the ear, produces a sound which is even painfully strong.

The readiness with which solids receive and transmit sound is further perceived in the fact, that a small musical box, while held in the hand, is scarcely audible, but when pressed against a table, or a door, will rival a little harp. The vibration communicated from the box pervades the whole of the wood, and the extended surface then acting on the air increases the effect. The construction of violins, harps, guitars, &c., and of sounding-boards generally, is governed by the same law. In the dancing-master's *kit* or small fiddle, which he carries in his pocket, there may be the same strings and the same bow as for a violin, but it has very little sound, because the extent of its surface is so small. A heavy piece of metal called a *sourdine*, when fixed upon the bridge of a violin, damps the sound, because it is a dead mass resisting the motion of the elastic wood.

The fact of solids conveying sound so much more perfectly than air, has lately been applied to useful purposes in medicine. Dr. Laenec, of Paris, proposed some years ago to listen to what was going on in the interior of the body, and of the chest particularly, by applying one end of a wooden cylinder, which he called a *stethoscope* or *chest inspector*, to the surface, and resting the ear against the other end. The results of this happy thought have been important.

The actions going on in the chest are, the entrance and exit of the air in respiration, the voice, and the motion of the blood in the heart and blood-vessels ;—and so perfectly do all these declare themselves to a person listening through the *stethoscope*, that an ear once familiar with the natural and healthy sounds, instantly detects certain deviations from them. Hence this instrument becomes a means of ascertaining certain diseases in the chest almost as effectually as if there were convenient windows for visual inspection : and when it is considered that a fourth or fifth part of the inhabitants of Europe die of diseases of the chest, such as inflammations, abscesses, consumptions, dropsical collections, aneurisms, and various affections of the heart and blood-vessels, each of which requires an appropriate treatment, the importance of such a means may be judged of. By many medical men this instrument was at first ridiculed as quackery and nonsense, and many have yet to learn the use of it. May not both of these facts be attributed to the error which has existed in medical education, of leaving so many practitioners without that knowledge of the general laws of nature, which should enable them to appreciate at once any means likely to be useful in their art, from whatever quarter offered?

“ *Velocity of sound.*” (See the Analysis.)

The velocity of light is such, that for any distance on earth its passage may be regarded as instantaneous. The velocity of sound is very much less.—If a woodman be observed at his occupation

on the hill, his axe is seen to fall a considerable time before the sound of his blow reaches the spectator's ear.—The flash of a gun fired at a distance is seen long before the report is heard.

Most accurate experiments have been made to ascertain the velocity with which sound travels in the atmosphere; and it is found to be 1,142 feet per second, or a mile in about four seconds and a-half; varying little either with the density or temperature of the air.

By noting then how long the flash of a gun is seen before the report reaches the ear, we learn the distance of the ship or battery from which the gun is fired. A chasing ship may thus often discover whether she be *nearing* or not the object of her pursuit. In the same manner the distance of thunder may be ascertained: and the reason of the long continued roll of thunder is, that although the lightning darts instantly through the chain of clouds, perhaps of miles in length, the claps or explosions at each interruption of the chain are only heard successively, as the sound arrives at the ear. The pulse at the wrist of a healthy man is a convenient measure of time for ascertaining distances by the motion of sound,—each beat marking nearly a second, and therefore indicating a distance of nearly a quarter of a mile.

A line of muskets fired at the same instant cannot appear a single report to any person who is not in the centre of a circle, of which the line forms a part.

An extended orchestra of musicians cannot be heard equally well from all situations near them.



Wind affects the velocity of sound just as a current in water affects the motion of a sailing ship.

Sound decreases in intensity from the centre where it originates, according to the same law as gravitation or light ; that is to say, at double distance it is only one-fourth part as strong, at triple, a ninth, and so on.

By confining it, however, in tubes, which prevent its spreading, its force diminishes much less rapidly, and it will therefore extend to much greater distances.—In many manufactories, and even private dwellings now, there are pipes for the conveyance of sound leading to all parts ; so that on ringing a bell to attract attention, verbal orders may be given through them to great distances.

Sound travels in water about four times quicker, and in solids from ten to twenty times quicker, than in air. The blow of a hammer given to a wall by a person at one end, may be heard twice by a person at the other, *viz.* almost immediately by an ear applied to the wall, and a little after through the air.

“ *Reflection of sound.*” (Read the Analysis.)

As a wave of water turns back at a smooth wall or obstacle, so that at any distance after the reflection, it appears what it would have been at the same distance beyond the wall, only moving in an opposite direction ; so the pulses or waves of sound are regularly reflected from flat surfaces, and produce what is called an *Echo*. Such flat surfaces of nature’s works are found only among the rocks

and hills ; and hence arose the beautiful fiction of the ancient poets, that Echo was a nymph who dwelt concealed among the rocks. Science has now disclosed the secret of the viewless Echo ; but who does not vividly recollect the wonder and delight with which he has listened, in the morning of his days, to his shrill call returned to him from some bold precipice, across the plain or river, or perhaps sent down to him again from the vaulted roof of ocean's caves !

The quickness with which an echo is returned to the spot where the sound originates, depends of course upon the distance of the reflecting surface ; and, as sound travels 1,142 feet in a second, a rock at half that distance returns a sound exactly in one second. The number of syllables that can be pronounced in a second will, in such a case, be repeated distinctly, while the end of a longer phrase would mix with the commencement of the echo. The breadth of a river may easily be ascertained where there is an echoing rock on the farther shore. A perpendicular mountain's side, or sublime cliffs, such as in many parts skirt the British coasts, return an audible echo of artillery, or of thunder, to a distance of many miles.

If two bold faces of rock or wall be parallel to each other, a sound produced between them is repeated often, playing like a shuttlecock between them, but becoming more faint each time until it is heard no more. In some situations, particularly when the sound plays thus above the smooth surface of water, a pistol-shot may be counted forty times.

The resonance of inclosed spaces depends on this continued reverberation. It often increases the effect of music by converting a simple melody, which is a *succession* of notes, into a harmonized piece, where each note is *accompanied* by softer accordant tones ; and a young flute-player is often first charmed with his own music when he finds himself performing a duett with Echo in a cave or under a spacious arch :—but resonance injures the distinctness of speech, so as even in some ill-contrived halls of assembly, or theatres, to render the articulation unintelligible. Small rooms or near surfaces give no perceptible echo, because the interval of time between the original sound and its repetition is too short for the ear to appreciate.

It is worthy of remark, that every apartment or confined space has a certain musical note proper to it, the pitch of which depends upon the number of pulses or repetitions of a sound produced there in a given time by the returns from its walls. The velocity of sound being uniform, this number must depend on the size of the apartment.

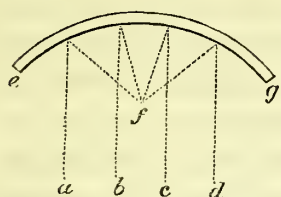
There is a curious effect of echo which both illustrates the nature of the phenomenon, and proves that a tone or musical sound is merely a repetition of pulses following each other very quickly. Iron railings are generally formed of square bars, of which any side is a plane surface, and may produce an echo. Now a sound, such as the sharp blow of a hammer, occurring near the end of such a railing, is echoed to a corresponding place on the other side by every bar in it ; and as the echoes do not return all at once, but in regular

succession according to the increasing distances of the bars, the consequent regular succession of slight pulses, with uniform and small intervals, affects the ear, not as the echo of a single blow, but as a continued musical tone, the pitch of which depends on the distance of the bars from each other. —The writer of this had observed, in passing on horseback along a particular portion of road, where there was first a piece of wall and then two pieces of paling with rails or bars of different width,—that there was from the wall a clear echo of the horse's cantering feet, and afterwards, opposite the palings, a ringing sound for every step of the horse. He at first concluded that the road there was singularly hard, although it did not appear so, and he slackened the horse's pace to save his feet, until observing one day that the ringing sound was of different pitch opposite the two pieces of paling, and so as to correspond with the different width of the bars, the true explanation occurred to him that the sound was an echo of the nature above described.

That an echo may be perfect, the surface producing it must be smooth, and of some regular form; for the wave of sound rebounds according to the same law as a wave of water, or a ray of light, or an elastic ball, &c., as explained at page 106, *viz.* perpendicularly to the surface, if it fall perpendicularly, but if it fall obliquely on one side, departing with an equal degree of obliquity on the other. To express this very important law shortly, we say that “the angle of reflection is equal to the angle of incidence.”—According to



this law, any irregular surface must break an echo ; and if the irregularity be very considerable, there can be no distinct or audible reflection at all. A



regular concave surface, on the contrary, as *e g*, may concentrate sound, and bring all which falls upon it, as from *a b c d*, to the same centre or *focus*, as at *f*, so

as to produce there a very powerful effect.

We thus see the reason why echo is much less perfect from the front of a house which has windows and doors, than from the plane end, or any plane wall of the same magnitude,—and why the resonance of a room is so irregular and indistinct when the room contains curtains, carpets, and other furniture, or a crowded assembly. Halls for music have generally plane bare walls. Theatres for the drama, again, have boundaries broken in all ways by rows of boxes, and various ornaments.

The concentration of sound by concave surfaces produces many curious effects both in nature and in art.

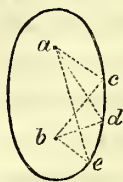
There are remarkable situations where the sound from a cascade is concentrated by the surface of a neighbouring cave so completely, that a person accidentally bringing his ear into the focus, is suddenly astounded, as if the universe were crashing around him. A chair placed in the cave, so that a person sitting down in it must bring his ear into the focus, insures the success of the sometimes amusing experiment.

The centre of a circle is the focus in which

(1.)

2 M

sound issuing from it is again collected after reflection: hence the powerful echo near the centre of a round apartment. An *oval* has two centres



or *foci*—one towards each end, as *a* and *b*—and the nature of the curve is such, that sound, or light, or heat, issuing around from either of the foci, as *a*, by obeying the law of reflection above stated, is all directed from the various points, as at *c d e*, &c., to the other focus, as at *b*. Hence a person uttering a whisper in one focus of an oval room is very audible at the other, although he may not be heard by persons placed between. Such a room may be called a *whispering gallery*. Concave surfaces facing each other, as two alcoves in a garden, or covered recesses on opposite sides of a street or bridge, will enable persons seated in their foci to converse by whispers across louder noises in the space between, and without themselves being overheard in that space.

The reason why a tube conveys sound so far, is, that its sides confine or repress, by a continued reflection, the advancing sound which in the open air would quickly spread laterally and be dissipated. And the reason that the plane surface of a smooth wall, or of water, &c., also conveys sound so far is, that it similarly prevents the lateral spreading and dissipation, although only on one side.—Persons far apart may converse along a smooth wall.—The barking of dogs, or the clear voice of a street-crier, in a town situated on the border of a lake, may be heard across the water in a calm evening, at a distance of more than five

miles—the sound of bells, of course, is audible much farther.—And in the stillness of night, even the splashing oars of a boat will announce its approach to persons waiting at a great distance.

If a sound-reflecting surface be curved inwards, that is, be concave, it not only prevents the spreading of any sound which passes along it, but is constantly condensing the sound by driving the external part inwards. Hence, in a circular space, such as a gallery under a dome, persons close to the wall may whisper to each other at all distances.

An *ear-trumpet* is a tube wide at one end where the sound enters, and narrow at the other where the ear is applied : its sides are so curved that, according to the law of reflection, all the sound which enters is brought to a focus in the narrow end. It thus increases many fold the intensity of a sound which reaches the ear through it, and enables a person who has become deaf to common conversation, to mix again with pleasure in society. The concave hand held behind the ear answers in some degree the purpose of an ear-trumpet, and in a very large theatre is sometimes useful even to persons of quick hearing. A notorious instance of a sound-collecting surface was the *ear of Dionysius*, in the dungeons of Syracuse : the roof of the prison was so formed as to collect the words and even whispers of the unhappy prisoners, and to direct them along a hidden conduit to where the tyrant sat listening. The wide-spread sail of a ship, rendered concave by a gentle breeze, is also a good collector of sound. It happened one day on board a ship sailing along the

coast of Brazil, far out of sight of land, that the persons walking on deck, when passing a particular spot, heard very distinctly, during an hour or two, the sound of bells, varying as in human rejoicings. All on board came to listen, and were convinced, but the phenomenon was most mysterious. Months afterwards it was ascertained, that at the time of observation the bells of the city of St. Salvador, on the Brazilian coast, had been ringing on the occasion of a festival : their sound, therefore, favoured by a gentle wind, had travelled over perhaps 100 miles of smooth water, and had been brought to a focus by the concave sail in the particular situation on the deck where it was listened to. It appears from this that a machine might be constructed having the same relation to sound that a telescope has to light.—A friend of the author, on the 18th of June 1814, while sitting near the wall of his garden, situated near Dover, heard distinctly the firing of the cannon at the battle of Waterloo.

The *speaking-trumpet* is made, according to the same law of reflected sound, with the view of directing the strength of the voice to a particular point. The sea captain uses it to hail ships at a distance, or to send his orders aloft, where the unaided voice would be lost in the noise of the wind and waves. A similar form of mouth is used for the *bugle horn* and common trumpet, and fits them to sound the note of command amid the uproar of contending armies.

Some amusing effects have been produced by operating on sounds with tubes and concave sur-



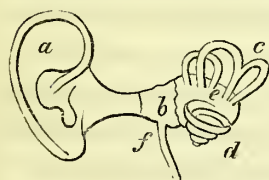
faces. What was termed the *invisible girl*, was a contrivance where the questions of visitors were caught by a concealed concave, and carried to the director who sat at a distance ; and his replies, as in the whispering gallery, became audible to the inquirers alone.

The concave, undulating, and perfectly polished surface of many sea-shells, fits them to catch, mix, and return the pulses of sounds that happen to be trembling about them, so as to produce that curious resonance from within, which closely resembles the sound of the distant ocean—so closely, that the spirited boy, after studying the interesting stories of voyagers which paint dangers to be nobly braved, and charms of nature to be seen in distant lands, often feeds his imagination with this voice of the shell, and fancies himself already riding among the billows.

### *The animal ear,*

so admirably adapted to perceive the evanescent tremblings of the air, has of course a structure in nice relation to their nature as now explained. The parts of the ear, and the progress of sound to the sentient nerve, may be simply described as follows.

1st. There is external to the head, a wide-mouth-



ed tube or ear-trumpet *a*, for catching and concentrating the waves of sound. It is moveable in many animals, so that they can direct it to the

place from which the sound comes.

2d. The sound concentrated at the bottom of

the ear-tube, falls upon a membrane stretched across the channel, like the parchment of an ordinary drum, over the space called the *tympanum* or *drum of the ear b*, and causes the membrane to vibrate. That its motion may be free, the air contained within the drum has free communication with the external air, by the open passage *f*, called the *Eustachian tube*, leading to the back of the mouth. A degree of deafness ensues when this tube is obstructed, as by wax; and a crack or sudden noise, with immediate return of natural hearing, is generally experienced when, in the effort of sneezing or otherwise, the obstruction is removed.

3d. The vibrations of the membrane of the drum are conveyed farther inwards, through the cavity of the drum; by a chain of four bones (not here represented on account of their minuteness), reaching from the centre of the membrane to the *oval door or window* leading into the labyrinth *e*.

4th. The labyrinth, or complex inner compartment of the ear, over which the nerve of hearing is spread as a lining, is full of water; and therefore by the law of fluid pressure (*see page 225*), when the force of the moving membrane of the drum, acting through the chain of bones, is made to compress the water, the pressure is felt instantly over the whole cavity, as in a hydrostatic press.—The labyrinth consists of the *vestibule e*, the three *semicircular canals c*, imbedded in the hard bone, and a winding cavity, called the *cochlea d*, like that of a snail-shell, in which fibres, stretched across like harp-strings, constitute the *lyra*.—The separate uses of these various parts are not yet

perfectly known. The membrane of the tympanum may be pierced, and the chain of bones may be broken without entire loss of hearing. Considerable diversity of form and dimension is found in different animals. The bone containing the cavities of the ear is the hardest in the body, and is the first formed.

The ear has the power of judging of the direction in which sound comes.—A person in a thicket listening to the song of various birds, although they be concealed from his eye by the luxuriance of the vernal foliage, still judges correctly by the ear in what tree every little songster is concealed.—The same truth is strikingly exemplified in the fact that, when horses or mules march in company at night, those in front direct their ears forwards; those in the rear, backwards; and those in the centre, laterally or across;—the whole troop seeming to be actuated by one feeling, which watches the common safety.

The intensity of sound is to the ear a measure of distance.—In a windy night, the sound of a distant bell may be brought so quickly, that it has not yet had time to spread and be weakened; and a person is often roused from a reverie by its unusual loudness and apparent nearness.—When a stormy wind blows directly upon a coast, and rolls the great waves in upon the sandy beach or among the rocks, the countryman living far inland hears the uproar, as if the ocean had burst its barriers, and were pouring in upon the land.—The scene-contrivers at our theatres heighten the illusion of an approaching procession, by letting

the accompanying music be first heard from a closed chamber or in a feeble tone, and afterwards with gradually increasing loudness. To the imagination, already excited perhaps to the highest pitch by the drama of some divine mind, the advancing host is thus most vividly portrayed; and when at last, with the thunder of drums and trumpets from the front of the stage, the troop also appears, the effect is complete.—It is the varying loudness of the *Æolian* harp which produces the feeling that the heavenly choir is sometimes approaching and sometimes receding.



### PART III.

(CONTINUED.)

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#### SECTION V.—DOCTRINES OF FLUIDITY IN RELATION TO ANIMALS.

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In the preceding sections on the laws of fluidity, occasional illustrations have been taken from the animal economy ; but there are many other particulars of the same class and of great interest, which it is convenient to consider apart under the four heads of, 1st, *The circulation of the blood* ; 2d. *The respiration and voice* ; 3d. *The digestion* ; and 4th. *The pelvic phenomena*. It is important to remark here, that this section cannot be understood by a person ignorant of those which precede.

##### THE CIRCULATION OF THE BLOOD.

PERHAPS there are few points more remarkable in the history of the progress by which man has arrived at his present knowledge of the universe, than that he was so long ignorant of the fact that the blood in his own and in other animal bodies is constantly circulating. England claims as one of her sons, the man whose powerful intellect at last established this truth, in opposition to strong appearances, and to the most fixed prejudices. Dr. Harvey published his proofs in the year 1619.

A person who tries to imagine what the science of medicine could have been while it took no account of this fact, on which, as a basis, much of the certain reasoning about the phenomena of life must rest, is prepared for what old medical books exhibit of the writhings of human reason, in attempts to explain and to form theories, while a fatal error was mixed with every supposition.—The chief circumstance which prevented the earlier discovery of the circulation was, that on examining dead bodies, the arteries were always found empty of blood ;—which was the reason, also, of those vessels being called *arteries*, or *air-tubes*.

We now know, that as the Thames water spreads over London in pipes, to supply the inhabitants generally, and to answer the particular purposes of brewers, bakèrs, tanners, and others, and is then in great part returned to where the current sweeps away the impurities ; so, nearly in the human body, does the blood spread from the centre, through the arteries, to nourish all the parts, and to supply material of secretion to the liver, the kidneys, the stomach, and other viscera ; and returns from these by the veins towards the heart and lungs, to be purified and to have its waste replenished, that it may again renew its course.

The circulation may be more particularly described thus. From the left chamber or *ventricle* of the strong muscular mass the *heart*, a large tube arises, called the *aorta* ; and by a continued division or ramification, opens a way for the bright scarlet blood to every the minutest part of the living frame,—the extreme divisions or twigs be-

ing so small, that they are called *capillary* or hair-like tubes. At the terminations of these vessels, the blood, after answering the purposes of general nutrition, &c., by which it loses its bright colour, enters the commencements of the *venous tree* or returning channel ; and gliding successively from smaller to larger branches, returns towards the right chamber or ventricle of the heart, requiring purification and partial renewal. Considering the great arterial and venous systems of the body as *twin trees*—the *scarlet* and the *purple*, with corresponding and meeting branches, and with trunks which touch each other at the heart—it will appear that they again similarly meet or inosculate by their extreme roots, and thus form a continued or circular channel. The root of the venous tree, by which the blood spreads from the right chamber of the heart through the lungs, is called the *pulmonary artery*, and that of the arterial tree, by which the blood returns to the left chamber, is called the *pulmonary vein*. Both of these ramify in the spongy masses of the lungs, forming a great part of the pulmonary substance. Fresh material for the blood is brought from the *digestive organs* by the *lacteal absorbents* and *thoracic duct*, and is constantly pouring into a large vein near the heart, to be completely mixed with the dark or returning blood by a violent agitation or *churning* during its passage through the heart. The mixture on leaving the right ventricle is strained through the minute ramifications of the vessels in the lungs, and at the same time is exposed to the action of the air entering the cells of the lungs in respiration, by

which exposure the dark purple blood becomes again pure scarlet, and when it reaches the left chamber or ventricle, is ready to set out on its journey as before, charged with new life and nutriment. The two chambers or ventricles of the heart have each an anti-chamber or *auricle* (so called from an external resemblance to a dog's ear), into which the blood is first received from the veins; and there are valvular doors between the auricle and ventricle, which allow the blood to pass readily into the ventricle, but oppose its recoil during the ventricular contraction. Similarly acting valves are placed between the ventricles and great arteries. There are valves also in many of the veins, over the body, to secure the natural course of the circulation. Besides the important change of purification which the blood undergoes in passing through the lungs, its composition is much influenced by the action of the kidneys, of the exhalants of the skin, and of the liver,—the two former relieving it from superfluous moisture and salts, the last, from a large quantity of matter in the form of bile.

The description given above of the circulation of the blood is only an outline; and yet by shewing the manner in which fresh material enters, it contains more than Harvey knew of the subject. In this department of knowledge, as in most others, we have advanced from the very general and vague, to the more particular and precise:—and just as the general nature of steam was known long before it served in steam-engines; and as the period of the moon's revolution had been accu-



rately observed for thousands of years before the fluctuations in her velocity could be calculated so as to make her the mariner's best guide in his courses across the ocean,—so, when Harvey had proved the general fact of the circulation of the blood, he had left much yet to be done, by observing and reasoning from subordinate facts, to render the knowledge available for the many useful purposes which it is calculated to serve. Within a few years only, has the importance of the subordinate circumstances been fully appreciated,—as is evinced by the numerous works composed to elucidate them; but many of which works have served only to prove, that if the difficulties were to be solved by natural philosophy, medical men in general had not yet studied it sufficiently to be able to use it successfully. In this section it will be attempted to place certain important points of the subject in a clear light; and by referring directly to the general laws of nature, as explained in the body of the work, to settle existing disputes on some of these points, to remove remaining doubts on others, and to suggest some important new applications.

The fact of the circulation of the blood being once admitted, an enquirer who contemplates the apparatus by which it is effected, is led by the general analogies of nature to conclude—1st. That the ventricle of the heart, at each contraction, empties itself into the great artery, as a forcing pump at each stroke empties itself into its pipe;—2d. That the consequent jet causes a wave to pass along to the extremities of the arterial tree (ac-

counted simply elastic), so as to produce every where what is called the pulse ;—3d. That the force of the heart, acting along the arteries, forces the blood through their open capillary extremities into the commencing veins, and along the veins back to the heart again. Now these assumptions, which Harvey believed completely to describe the circulation, are all nearly true : but are still so far from being either the exact or the whole truth, that they leave important facts unexplained. Thus :—1st. The pulse, instead of being the wave, as slowly progressive as the view above given anticipates, is almost as instantaneous over the whole body as a shock of electricity ;—2d. The arteries are all found empty after death, although they have no power of emptying themselves ; and if an artery be tied in the living body, the part beyond the ligature, and cut off therefore from the influence of the heart, is equally emptied ;—3d. The rapidity of the blood's passage through the capillaries varies very much, but it does not vary in exact accordance with the changes in the rapidity or force of the heart's action.—These and other facts, ascertained since Harvey's day, not exactly squaring with his views, have rendered farther investigation necessary ; and it is now additionally known—1st. That the coats of the arteries are not simply elastic but actively contractile ; and 2dly. That the capillary vessels can move the blood independently of the heart. In analysing this subject, it is convenient to follow the blood round from the heart to the heart again, through the three stages of, 1st. *The arteries* ; 2d. *The capillaries* ; 3d. *The veins*.

*Motion of the blood in the arteries.*

The contractions of the heart inject the blood into the arteries with a force maintaining such a tension in them, that, according to the interesting experiments of Dr. Hales, recorded in his *Statical Essays*, if any artery of a large animal like a horse be made to communicate with an upright tube, the blood will ascend in the tube to a height of about ten feet above the level of the heart, and will there continue, rising and falling a few inches with each pulsation of the heart. Now a column of *ten* feet, as explained at page 260, indicates a pressure of about *four and a half* pounds on a square inch of surface : this, therefore, is the force of the heart urging the blood along the arteries into the veins.—The opposing tension of the veins is much less, because, as will be explained under the proper head, the blood readily escapes from them into the heart : Hales found that in a tube communicating with a vein, the blood stood only a few inches higher than the level of the heart. In small animals he ascertained the tension of artery and vein to be less than in large ones; and the ratios deduced for the human body, under ordinary circumstances, were eight feet column, or nearly four pounds per inch for the arteries; and half a foot column, or a quarter of a pound per inch for the veins.

Arteries examined after death are found to consist of,—1st. an outer coat of strong *elastic substance*; 2d. a middle coat of *circular fibres*; and 3d. an inner coat of *smooth lining membrane*. Their elasticity or power of resisting change of dimen-

sion, and of returning to a middle state from either dilatation or compression, because remaining in the dead artery, was the most obvious property, and was that first attended to. Minute observation of the phenomena of life has since determined the following facts, proving and illustrating a contractility resident in the fibrous coat.

1. A small living artery, cut across, soon contracts so as to close its canal, and arrest hemorrhage.

2. While an animal is bleeding to death, the arteries, in accommodating themselves to the decreasing quantity of blood, contract far beyond the degree to which their simple elasticity would carry them; and they relax again after death. Dr. Hales took seventeen quarts of blood from a horse before it died, in whose body only three quarts more were found altogether, and yet the moment before death the tension of the arteries sustained a column of two feet of blood in his experimental tube.

3. The artery of a living animal, if exposed by dissection to the air, sometimes will contract in a few minutes to a great degree: and in such a case, only a single fibre of the artery may be affected, narrowing the channel like a thread tied round it. (*See Parry on the Pulse.*)

4. When a living artery is tied, the part between the ligature and the nearest branch on the side of the heart gradually contracts, and becomes at last a solid or impervious cord.

5. Fluctuation in the vital action of parts, is often attended with sudden increase or diminution of calibre in the arteries concerned.



Although these facts prove indubitably a contractility in the coats of arteries distinct from their elasticity, still, because the circular fibres do not resemble common muscles in colour or in chemical composition, or in being immediately obedient to the stimuli of electricity, pricking, great heat, &c., their contractility was by many persons for a long time denied. The dispute, however, was often more about the words *contractility* and *muscularity*, than about facts.

The pulse in the arteries, chiefly as regards its almost instantaneous occurrence over the whole system, in all states of arterial dilatation, and its great strength and sharpness in very small and remote branches, points also to the active contractility of the arterial coats : for,

1. Were the arterial tree in the living body a system of simply elastic tubes as readily admitting of farther dilatation as in the dead body, the first part or trunk would affect the motion of the blood beyond it, nearly as the *air-vessel* (see page 332) placed at the commencement of artificial arrangements of water-pipes affects the motion of the water in them ;—that is to say, as the air-vessel converts the sudden and interrupted jets of water from pumps of *fire-engines*, *town-supplying pipes*, &c. into a uniform stream with scarcely a remnant of shock, so, in the arterial branches, simple elasticity would cause a more tranquil flow than indicated by the remarkable gushes from a wounded artery, and a quieter beat than that bounding pulse of life felt in the remote artery of the wrist, as sensibly, in proportion, as near the heart itself.

2. Were the pulse a wave advancing in tubes that yielded as readily as the dead arteries in their middle states of dilatation, it would be more slowly progressive from the heart to the extremities ; but it is felt so instantly over the whole body, as to be commonly compared to a shock of electricity.

3. A pulse may be produced artificially in the arteries of a body recently dead, by filling them with water to the tension of life, and then injecting at intervals, by a syringe, as much water as the heart throws of blood at a beat ; but although the artery is then distended nearly to the limit of its dilatability, and is therefore rendered rigid, the beats are weaker than those of the living pulse. A similar experiment, tried by connecting the artery of a dead animal with the corresponding artery of a living one, has a similar result.

4. A tube, extensively elastic, that it might convey a wave of liquid with a velocity approaching to that of the pulse, would require to be so tense, from fulness, as to be discernible always by the touch, through any imbedding medium, such as flesh, like a hard cylinder or cord ; and it would be acting constantly as a spring tending to straighten itself, and therefore would be stiffening the parts through which it passed. Now the living arteries, between their pulsations, are almost as soft and compressible as the surrounding flesh, and they offer no perceivable opposition to bending, in any movement of the parts. This may be verified by examination of the lips, for instance, or of the fingers ; but when a person sits cross-legged, the well-known shaking of the suspended foot, in

unison with the pulse, shews the recurring efforts of the artery to straighten itself, during the moments of greater tension.

5. A bulky wave in elastic vessels would have to recoil from the extremities, or to pass through them as a gush; and the recoil would be particularly observable near the ligature of a tied artery: but examination has not detected such effects in the living body. The operation for aneurism,—in which the artery is tied *beyond* the tumour, instead of, as usual, on the side next the heart,—if it checked a strong wave, would almost certainly produce bursting; yet Mr. Wardrope and others have lately performed this operation with successful issue.

6. The wave would be more interrupted by the bandage in the operation of bleeding, than the living pulse is.

7. The pulse of a paralytic limb often seems more affected than mere change of size in the artery will account for. The same is true, in an opposite way, of the pulse in an artery leading to an inflamed part.

8. If the abdomen of a living animal be opened, the mesenteric artery, in all its ramifications, is seen stiffened and raised up suddenly with every pulsation, in a manner which the spreading of newly received blood in a very yielding vessel does not account for.

9. In the interesting experiments of *Bichât*, *Parry*, and others, to ascertain the exact extent of the supposed dilatation and contraction of arteries during a pulse, not the slightest degree of

either was discernible, even when sought for with microscopes.

To explain these and other phenomena, then, it seems necessary to admit, as occurring throughout the whole body, and almost simultaneously with the contraction of the heart itself, such an action of the contractile fibres of the arteries, as to modify the elasticity of the arteries, and to render them rigid enough, in all degrees of dilatation, for the heart to produce its effect through them almost as it would through tubes of metal.—Dr. Young, in a paper published in the *Philosophical Transactions* for 1809, and characterized by the usual elegance and precision of his writings, has adduced experiments and calculations, to shew that waves in elastic vessels advance more quickly than was before imagined; but the spreading of the pulse seems to be yet more rapid than his calculation anticipates.—It is evident, that when arteries, in consequence of depletion, are contracted beyond the middle station of their elasticity, their tension and power of quickly conveying the pulse must be dependent altogether on the condition of their contractile fibres.

The careful experiments which could detect no change of size in the arteries during the pulse, while they disprove the ancient belief of a considerable tumefaction or wave passing along, or of a considerable filling and emptying of arteries, like what occurs in the heart, might also be supposed positively to disprove the occurrence of any general constriction of the vessels on their contents—but erroneously: for if a man's arterial



system, considered as one cavity, be supposed to contain five pounds of blood (which is near the truth), and if the vessels be thought to embrace their contents, even between the pulses, with force enough to have all a rounded or cylindrical form, although remaining soft and yielding to the pressure of the finger ; and if we suppose their coats, during the pulse, to be thrown into a sudden contraction, as if in obedience to an electrical shock, still, because blood is incompressible, and because just as much enters the arteries with every pulse as escapes from them before the next, their bulk would not sensibly diminish by the strongest conceivable action of their coats ; of which action the only sensible effects would be, that the soft, yielding, and, in some places, compressed tubes would be suddenly converted into hard or resisting cylinders ; and that wherever, by any accidental pressure, an artery had been flattened, it would, in regaining its cylindrical form, strike or pulsate against the compressing body.—Whether such an action as this contributes to produce the arterial pulse will be considered under the head of “ *the pulse*,” after we have seen how the blood moves in the capillaries and veins.

In any admissible view, however, of arterial agency, we find that the arteries contribute to the circulation of the blood, but as tubes which convey it, their own permanent tension, and therefore the force with which the blood is pressed into the capillaries, being derived from the heart alone. Even if there be a momentary arterial contraction, such as alluded to above, at the instant of the

pulse, it is of too short duration to have an appreciable effect, and probably any effect would be counterbalanced by the same action pervading the capillaries. Many physiologists have had a confused belief that the arteries aided very actively in propelling the blood; but a little reflection would have shewn, that as they have no vermicular or progressive contraction, like the intestines, they no more *propel* the fluid within them, than any other tubular conduits do.—Although they be thus in no degree instrumental in the propulsion of the blood, still by more permanently enlarging or diminishing their calibre, that is, by merely becoming larger or smaller conduits, they may much influence its local distribution, and the speed of its transmission.

The nature of this work does not allow us to record historically the various errors into which even able men have fallen, in attempting to explain the office of the arteries, but we shall glance at the following.—*Dr. Monro* and *John Hunter*, two of the most able physiologists that the world has seen, believed that the arteries did almost as much in propelling the blood as the heart itself. We need not repeat the refutation of this opinion. The ingenious *Bichât*, again, unable to detect either momentary contraction or dilatation in the arteries, thought that the blood was pushed along them by the heart, instantly through their whole extent, as a solid rod of metal or wood is advanced by an impulse at one end. *Dr. Parry* took nearly the same view of the subject, and illustrated his idea by referring to the experiment of moving a

whole line of billiard-balls by striking the extreme one. Both these authors erred by neglecting the hydrostatical truth, that pressure in a fluid operates equally in all directions, and therefore that fluid pressed into a tube, tends to dilate the tube, just as powerfully as to drive the fluid forward : and they did not advert to the fact that the progress of the blood in the small arteries is not by waves or successive jets, but is nearly a uniform stream. The blood could only advance, as they supposed, by the arteries becoming, for an instant, absolutely rigid, in consequence of a strong action of their contractile fibres.

It merits notice here, although not strictly a mechanical fact, that arteries permanently increase or diminish in size when a permanent change takes place in the demand for their service. The arteries of the *gravid uterus*, or of an increasing tumour, grow with the part supplied, while on the contrary, those of a stump left after amputation, soon remarkably diminish. If the chief artery of a limb be obliterated by any cause, as after the operation for aneurism, the small collateral anastomosing branches increase in size to do its duty.

It is further remarkable, that when arteries are called upon to carry an increased quantity of blood, they often become tortuous or serpentine, as well as larger ; and that arteries leading to parts whose actions are naturally intermitting or fluctuating, have generally the tortuous form. Of these truths, the arteries leading to rapidly growing tumours, or to varicose aneurisms, and the arteries of the uterus and testes, may serve as instances.

This bending of arteries, and the very curious division into many branches which again re-unite, found in those leading to the brains of some animals, do not seem intended to slacken the rapidity of the sanguineous current, but to give the artery a greater control over the supply.

*Passage of the blood through the capillaries.*

We have seen that the heart keeps up a tension or pressure in the arteries, of about four pounds on the square inch of their surface ; and with this force, therefore, is propelling the blood into the capillaries. If these last were passive tubes, constantly open, such force would be sufficient to press the blood through them with a certain uniform velocity : but they are vessels of great and varying activity ; it is among them that the nutrition of the different textures of the body takes place, as of *muscle, bone, membrane, &c.*, and that all the secretions from the blood are performed, as of *bile, gastric juice or saliva, &c.* ; and to perform such varied and often fluctuating offices, they require to be able to control, in all ways, the motion of the blood passing through them. The capillaries of the cheek, under the influence of shame, dilate instantly, and admit more blood, producing what is called a *blush* ;—under the influence of anger or fear, they suddenly empty themselves, and the countenance becomes pallid—tears or saliva, under certain circumstances, gush in a moment, and in a moment again are arrested—if a person having inflammation in one hand be blooded from corresponding veins in both arms at the same



time, twice or thrice as much blood will flow from the diseased side as from the other. Similar changes occur in many other instances. Now the only action of cylindrical vessels, capable of causing these phenomena, is contraction and dilatation of their coats; and with reference to such action it merits notice, that arterial branches have more of the fibrous or contractile coat in proportion as they are smaller.

A muscular capillary tube strong enough to shut itself against the arterial current from the heart, is also strong enough to propel the blood to the heart again through the veins, even if the resistance on the side of the veins were as great as the force on the side of the arteries. For if we suppose the first circular fibre of the tube to close itself completely, it would, of course, be exerting the same repellent force on both sides, or as regarded both the artery and vein. If then the series of such fibres forming the tube were to contract in succession towards the vein, as the fibres of the intestinal canal contract in propelling the contents of that canal, it is evident that all the blood in the capillary would thereby be pressed into the vein towards the heart. If after this the capillary again relaxed on the side of the artery, so as to admit more blood, and again contracted towards the vein as before, it would produce a forward motion of the blood, first towards the vein, and then in it, independently of the heart. As capillary action, however, is not visible, its nature has not yet been positively ascertained:—some persons have deemed it electrical.

It is capillary action which absorbs and moves the fluids of the classes of animals which have no heart. It must also be the power which moves the blood in warm-blooded monsters formed without hearts. There are cases of apparent death among human beings, where the heart remains inactive for days, and yet a degree of circulation sufficient to preserve life is carried on by the capillaries. In illustration of capillary action, we have also the absorption, by the lacteals, of nutriment from the alimentary canal; and perhaps, to a certain extent, the circulation of the blood in the livers of animals. In this last case, the blood collected by veins from the abdominal viscera, instead of going directly to the heart, is again distributed through the liver by the branches of the *vena portæ*, and is then again collected by the ordinary veins of the liver, and carried to the heart: it thus moves through two sets of capillaries in passing from the arteries to the heart again.

The action of the capillaries is the cause of that singular fact which prevented the ancients from discovering the circulation of the blood, *viz.* the empty state of the arteries after death. All the muscular parts of an animal, including, therefore, the contractile coats of vessels, retain their life, or power of contracting, for a considerable time after respiration has ceased,—as is seen in the recovery of persons apparently drowned or suffocated; in the leaping of a heart taken from an animal recently killed; in the actions resembling life which can be produced, by the agency of galvanism, in a body recently dead: but the fact

is seen still more aptly for our purpose, in the total disappearance of a local inflammation after the death of the patient,—for inflammation involves a gorging or over-distension of the capillaries, into which when the heart has ceased to press blood, the contractile force remaining in them, even under disease and in a dead animal, is sufficient to squeeze the blood out of them, and often to remove all trace of the malady which has been fatal.—In ordinary cases, then, the capillaries throughout the body remain alive and active for a considerable time after breathing has ceased, working like innumerable little pumps, and emptying the arteries into the veins. As the red blood is their proper sustenance as well as stimulus, they work as long as there is any of it coming into them from the arteries behind; except, however, the capillaries of the lungs, which soon cease to act, because, after breathing has ceased, they receive only black blood, and are moreover compressed by the collapse of the chest; and all the blood accumulates behind them. The capillaries may continue to be filled from the arteries, either in consequence of their elasticity opening them with what is called a suction power, or of an absorbent power dependent on life, like that of the lacteals and of the absorbents all over the body, and perhaps, of the vessels in the roots of vegetables. When death is produced by lightning, or by the poisons which destroy all muscular irritability, and therefore that of the capillaries, the arteries after death are found to contain blood like the veins. In a living body, if an artery be tied,

the part beyond the ligature is soon emptied into the veins, and becomes flat.—The experiment has been made even upon the aorta itself.

The empty state of the arteries after death has been ascribed, by some teachers, to the momentum with which they supposed the blood to be thrown out from the heart in its last contraction—sufficient, said they, to squirt it fairly through the most distant capillaries; a doctrine exemplifying the carelessness with which men sometimes receive and repeat opinions, to which their attention has never been fully awakened. Such an effect would not follow, even if the action of a dying heart were the strongest possible; while, in reality, it is in most cases so feeble, that the pulse for some time ceases to be perceptible at the extremities, and the diminished circulation lets them become cold.—Other physiologists have taught that an artery is capable of contracting directly upon its contents, so as to expel even the last drop;—but large arteries, when emptying, do not contract *roundly* like an intestine: they become *flat* like elastic tubes of leather *sucked* empty, and no contractile action of the vessel itself could bring its sides together in such a manner. If arteries emptied themselves by their own action, the pulmonary artery should be more certainly empty than the aorta, because it is shorter: yet it is always full; for the reason already stated, that the pulmonary capillaries cease to act after respiration has ceased, on account of the blood in them being venous or dark blood, and therefore not life-supporting or stimulant to them.



*Passage of blood through the veins.*

The veins have much thinner coats than the arteries, and if taken altogether have much greater capacity: for besides being larger than the corresponding arteries, they exist, in many situations, as double sets, an exterior and an interior: they have also very frequent inosculations or communications with each other throughout their whole course.

The simple weight of the column of blood in any descending artery is just sufficient to raise the blood through open capillaries to an equal height in the corresponding vein, according to the hydrostatical law, that fluids attain the same level in all communicating vessels; and therefore, as the arch of the aorta rises considerably above the heart, the gravitating pressure of the descending arterial column of blood would be sufficient to lift that in the veins not only up to the heart, but considerably beyond it. In addition to this influence of gravity on the venous current, the blood is pressed into the arteries, and from them therefore towards the veins, with a force from the heart itself, as stated above, of about four pounds to the square inch, or, in other words, as if there were a column of blood eight feet higher than the heart urging the current. It might be expected from the law of equal diffusion of pressure in fluids, that these causes would soon produce a tension in the veins as great as in the arteries: and this does not happen, only because the blood has a ready escape from the veins through the right ventricle of the heart. Under ordinary circumstances, there can be no greater tension in the veins than what is

sufficient to lift the blood to the heart and to overcome the friction ;—as in an upright leathern tube, open at top, and receiving water at its bottom, from a powerful forcing pump, there never can be greater tension or pressure than what corresponds to the height of the fluid column in the tube, and to the friction between the fluid and tube. In Dr. Hales's experiments, already alluded to, a tube connected with a vein so as to receive its blood, became filled with blood to a height only of about six inches above the level of the heart. As Dr. H. generally cut the vein completely across, and inserted the tube into the portion leading from the capillaries, he would have discovered the whole power with which the blood is pushed along the veins from the capillaries, but for the free lateral communication of veins with each other, which reduces the tension even in an obstructed branch, to the degree existing in the system generally. When from agitation of the animal, or any straining exertion, the passage of the blood into the heart was impeded, all the veins became tense, and a tube inserted into the returning jugular had blood running over, at a height of three feet above the heart.

If the blood did not escape from the veins, as above described, the only cause which could prevent the venous tension from becoming as great as the arterial, would be obstruction in the connecting capillaries : but the following facts and considerations prove that these vessels, which in the dead body allow the passage of injections, in the living body freely allow the passage of blood.

1st. Majendie laid bare the chief artery and vein of a living limb, and at the part, detached them from the flesh underneath, so that he could apply a tight bandage round the limb without including them, and could thus render them the only channels of circulation for the limb beyond the bandage. He then found, that when a separate ligature was put upon the vein, to prevent the return of its blood to the heart, and a puncture was made beyond the ligature, the flux of blood from the puncture was rapid or slow, according as the heart was allowed to produce a greater or less degree of tension in the artery :—this tension was regulated by his compressing the artery between the fingers.

2d. After a similar preparation of the parts, the blood will ascend in a tube from the obstructed vein very nearly as high as from the artery.

3d. In the common operation of bleeding, at the moment of puncturing the vein, the blood often jets from it as from an artery, staining even the top of the bedstead.

4th. The microscope discovers in the capillaries, a uniform forward motion of the blood, as if it were obeying the steady pressure of the arterial tension, and not any intermitting action.

5th. Disturbed action of the heart, by obstructing the passage of the blood through it, is very soon attended with a tumefaction of all the veins leading to the heart: the tumefaction becomes very visible about the neck and head, and in the liver produces swelling and acute pain.

6th. Dr. Young, from experiments made by him, and reported in the *Philosophical Transactions* for 1809, concluded, that perfectly open capillaries, of the size existing

in the living body, should just retard a flow of blood urged by the usual arterial tension, in the degree which really occurs:—a correspondence proving that they must be open; and open vessels, however small, and how slowly soever they transmit the blood, still, if the escape of blood from the veins were arrested, would transmit the arterial tension without diminution. 7th. The fact that after death the capillaries empty the arteries into the veins, proves that, under certain circumstances, the venous tension may become even greater than the arterial.—These facts, then, and others that might be mentioned, prove incontestably that the blood is pressed into the veins from the arteries and capillaries, with force sufficient to lift it, not only to the heart again, but many feet farther, *viz.* about as far as it would ascend in a tube rising from the tense arteries themselves. So little, however, has this important truth been understood, that in elementary works of authority lately published, the venous current is treated of as a very obscure subject; and some authors, in their anxiety to explain it, have assigned causes for it, which, as will appear hereafter, are positive absurdities in physics. The difficulty in the question seems to have arisen from the great disparity observed between the tension in the arteries and in the veins, while the reflection did not occur, that the disparity was owing to there being a free passage or outlet from the veins through the heart.

The illustrious Bichât, with an inattention to facts, extraordinary in him, persuaded himself that the influence of the heart ceased entirely at the ca-



pillaries, and that the blood was returned through the veins by the action of the capillaries alone. How could he avoid the single reflection, that, if the purpose of the arteries had been merely to convey the blood *to* the capillaries, and not also to bear the force which pressed it *into* and *through* them, the extraordinary strength of the arterial coats, and the great power of the heart to fill them and keep up the tension described, would have been quite superfluous?—and he knew that nature does nothing in vain. The reflection applies strikingly to the pulmonary artery, of which no branch exceeds a few inches in length.

The uniform current of blood along the veins, so apparent in the operation of bleeding, and produced, as now explained, by the combined influence of the heart and capillaries, suffers a considerable disturbance in the neighbourhood of the heart from three causes. 1st. As there is no valve between the veins and the auricles of the heart, each contraction of the right auricle tends to throw the blood back into the veins, as well as forward into the ventricle, and thus produces the venous pulse often felt in the neighbourhood of the chest. 2d. When the chest is expanded by inspiration, it is more roomy than during the collapse of expiration, and the blood then enters it more readily. 3d. While the chest is *inhaling* or *drawing in* air, that is to say, expanding so as to diminish the tension or pressure of the air within it (see *Pneumatics*), it is by the same action favouring the entrance of blood through the veins towards the heart placed in it;—on the contrary,

while it is *exhaling* or *throwing out* air, it is, with equal force, resisting the entrance of blood, and slackening, or even causing recoil of the inward current. This favouring or resisting force, however, as will be hereafter shewn, is only such as to lift or support a column of blood of about half an inch in height.—It appears then that the entrance of blood into the chest fluctuates by reason of the respiration, &c., as the entrance of a river stream into the sea fluctuates by reason of the ebbing and flowing of the tide. An eye watching the jugular vein, under favourable circumstances, may see it tense or slack in accordance with the opening and shutting of the chest.

It still remains to be ascertained whether or not veins have in themselves any active contractile power, such as can partially empty a lower portion into a higher portion beyond an adjoining valve. If so, the valve, by then bearing the pressure, would let more blood be easily raised from below into the portion so relieved: and the action, without being equal to the office of completely emptying any portion of a vein, would still have the effect of dividing a long heavy column into a number of short columns of comparatively little resistance. It is certain, at least, that the valves in the veins, by preventing the falling back of blood which has once passed towards the heart, must affect its flow during bodily exercise; for every time that pressure is made on a vein by a swelling muscle or otherwise, the blood in the part must be forced forward, and cannot return.

The veins which are surrounded by muscles are

thinner and weaker than those supported only by the skin. The external veins of the legs are almost as strong as arteries. Proving, however, that the fabric of veins is much weaker than that of arteries, any vein in the living body made to communicate directly with an artery, soon exhibits what is called a *varicose aneurism*, and swells to bursting. Veins possess power, to a great extent, of adapting themselves to the varying quantity of blood.

Some recent authors, as stated above, either not aware of the facts which prove that the blood is every where pressed into the veins, with force much more than sufficient to raise it to the heart again; or being unable, from their little familiarity with mechanical science, to draw exact conclusions from the facts, or to avoid errors in their own hypotheses, have promulgated the opinion that the progression of the blood in the veins is greatly owing to a partial vacuum or a suction-power in the heart or chest; that is to say, to the atmospheric pressure remaining constant on the body generally, while it is at intervals lessened about the heart. Now the whole influence of this effect or circumstance, as stated above, is merely a slight disturbance of the uniformity of the venous current near the chest.—Such a doctrine could not be proposed or entertained for a moment by a person understanding the principle of a common household pump; and its having been published, and tolerated by certain professional men in the present time, will remain a proof to posterity of the deficiency, as regards fundamental science or natural philosophy,

now existing in the ordinary medical education. Much ingenuity has been wasted upon it, particularly by Drs. Carson and Barry, the latter of whom, after making laborious experimental investigations on living animals, has even attempted to build upon it a superstructure of medical theory and practice! To say that the influence of the heart or chest is the power which draws the blood to the heart from the general system, is as if one asserted that the rising and falling of the tide at the mouth of a river is the power which collects the tributary streams in the interior country.

We shall enter into a little detail on this subject, because the discussion will elucidate some minor points connected with the circulation.

Presuming, then, that the reader perfectly understands the theory of pumps, and therefore of atmospheric pressure, as explained under *Pneumatics*, he will readily understand the two following propositions, either of which proves it to be a physical impossibility, that a sucking action of the heart or chest can be a cause of the blood's motion along the veins. 1st. The veins are pliant tubes free to collapse, and no pump can lift liquid through such. 2d. The *suction-power* of the chest in healthy respiration is too weak to lift liquid even one inch through tubes of any kind.

A practical illustration of the first proposition is afforded by putting the point of a syringe into a piece of gut, or eel-skin, or vein filled with water, and then trying to pump up the water. The result will be, that the fluid close to the mouth of the syringe will enter it, and then the



sides of the pliant tube will collapse against the syringe, making an end of the experiment. In exact proportion to the rigidity of the tube will be the distance to which the influence of the syringe will extend in it: if, for instance, half an ounce of pressure on the square inch of its surface be required to make it collapse, then the pump will draw up one inch of water, and so for other proportions. If during the action of the syringe, the tube were allowed to open freely at the bottom into a vessel of water, instead of the syringe then drawing any more water from the vessel into the tube, the original contents of the tube would straightway be discharged downwards into the vessel.

The explanation of all these facts is found in the pressure of the atmosphere (see from page 345 to page 360), seeking entrance every where at the surface of the earth, with a force of fifteen pounds per square inch, and overcoming any opposing force less than this;—a pressure which is sufficient, therefore, to push a column of water of thirty-four feet in height, up through a rigid tube into the vacuum of a pump, but will cause the sides of the tube to collapse, unless able to sustain its force. When nature intends a tube to resist any degree of suction, the tube is made rigid in proportion;—witness the wind-pipe and its branches, which are the only instances in the human body. And if tubes prepared for sucking light air only, have received such rigidity, how much stronger would tubes have been made for sucking blood.

Some bad reasoners on this subject have believed,

that if a suction power exist, capable of lifting one inch of a column of liquid, any column, however long, must follow the first inch when acted upon by the power; for, say they, the atmospheric pressure, by preventing a vacuum, will prevent separation of the liquid. Now, in the first place, this reasoning is quite inapplicable to pliant tubes, because the ready collapse of their sides will both allow the separation and prevent the vacuum; and in the second place, with respect to rigid tubes, it is equivalent to asserting that a force just capable of lifting one link of a chain, must therefore be able to lift any number of connected links. Water in a rigid tube, to which air has no admittance, may truly be considered as a chain, for it is held together by a force of fifteen pounds per inch, pressing inwards at the two ends: and any force, inferior to this, cannot lift one portion of it away from another, and therefore cannot draw out a drop but by lifting the whole. A man cannot suck any water from a rigid tube, which is closed at the bottom; and if the bottom be open, and he has not power to support the whole contained fluid, it will sink from his tantalized lips to stand at an elevation corresponding to his suction power.

To illustrate the second proposition respecting the trifling suction-power really residing in the chest, we may state, that a person of ordinary strength, using the whole power of the chest (but not of the mouth separately, which is a smaller and much more powerful pump than the chest), cannot through a rigid tube suck water from more

than about two feet below his lips, and therefore not half way so far as from the extremities of his body; while in the opposite action of blowing outwards, as in the attempt to blow through a tube which is dipping into water, he finds nearly the same limit. But in ordinary breathing, instead of force corresponding to a liquid column of two feet, or a *fifteenth* of the atmospheric pressure, the increase and diminution of air-density in the chest is measured by a column of less than one inch, or about a *five-hundredth* of the atmospheric pressure. This fact is easily shown by breathing through the nose, while holding in the mouth one end of a glass tube, the other end of which is immersed in water, and then noting how much the water in the tube rises above the surrounding level during *inspiration*, and sinks below it during *expiration*. The mouth during this experiment may be considered as part of the general cavity of the chest, to and from which air is passing by the narrow openings of the nostrils. In tranquil breathing, with both nostrils open, the fluctuation in the tube is less than half an inch each way; with one nostril closed, and the other a little compressed, it may amount to a whole inch; and with hurried or convulsive breathing, like that of an animal in terror or in pain, it may exceed twelve inches. Although the measures thus obtained from the mouth are somewhat too small for the changes in the chest itself, because the chest is more remote from the opening by which the external air enters, the difference is very trifling, as may be proved during such experiments by stopping the nostrils

altogether, while the same respiratory efforts are continued ; and as is also proved by the agreement of the results with strict calculation founded on the inertia and velocity of the air respired—a calculation similar to that required in adjusting the index to the machine mentioned at page 454, for measuring water-currents. In common healthy breathing then, while the mouth is open, the fluctuation of pressure in the chest would be measured by less than half an inch motion each way of the liquid column. Dr. Barry, not aware that this point could be so easily determined by the bloodless experiment described above, or even by a simple calculation, sought the solution by numerous trials on living animals, into some part of whose chest he forced a tube. But even if farther experiments had been at all necessary, those of Dr. B. could not have decided the question, first, because the pain and agitation of the dying animals rendered the breathing violent or unnatural ; and secondly, because his experimental tube often or always became a syphon, and he, not adverting to this fact, has not recorded the difference of level in the liquid at the two ends. That the external level was for the most part higher than the internal, is proved by his having noticed almost solely the *inhaling* action of the chest, although the *exhaling* is often a more powerful effort.

Calling an inch column of blood, then, the measure of the greatest sugescent and repellent powers of the chest during ordinary respiration, we see that the force which really sends the blood from below to the heart, may have to lift a column one



inch shorter during *inspiration*, and one inch longer during *expiration* : but this is the full and true measure and nature of the influence of the respiration on the blood's return to the heart. To say then that the atmospheric pressure, modified by respiration, is the great power which moves the venous blood, is just as if we said, that a boy standing near the fly-wheel of a steam-engine of a hundred horses power, and giving it his Lilliputian thrust, alternately backward and forward, were the prime mover of the machinery.

The truth explained above, that no kind of pump can lift fluid through pliant tubes, free to collapse, like the veins, renders it unnecessary farther to speak here of the pumping action of the heart itself, insisted on by Dr. Carson ; or of that other action, mentioned in a subsequent part of this work, to which also he attributes great influence, *viz.* the tendency towards a vacuum external to the lungs and around the heart, produced by the disposition of the lungs to collapse. It may be remarked, however, that this last influence is more considerable than the simple inspiratory action dwelt on by Dr. Barry, and that it operates during expiration nearly as much as during inspiration, varying in force with the degrees of expansion of the chest. It is weaker in the living than in the dead body, because the rigidity of the distended pulmonary arteries helps to support the weight of the living lungs.

Were it necessary to give proofs, to persons unable to follow the above argument, that a suction-power in the heart or chest is not the force

which draws the blood from the extreme veins, reference might be made to many notorious facts quite incompatible with that supposition; such, for instance, as those recorded at page 565; and others. A vein tied, fills tensely below the ligature—a vein cut across bleeds from the orifice which is distant from the heart, and will fill a lofty tube connected with it—the circulation goes on in persons holding their breath—the veins of fishes, which do not breathe, return the blood as well as those of men, &c. &c.

After the explanations now given, it is almost superfluous to remark, that *absorption* in animals cannot depend on atmospheric pressure, and that the effect of cupping-glasses applied to extract blood, or to prevent the absorption of poison in wounds, in no way depends upon the fluctuating density of the air in the chest. Dr. Barry's reasonings upon these subjects involve the same fallacies as his reasonings on the venous current. With respect to absorption, they neglect the fact of fluids having weight; and with respect to cupping-glasses, of which the true action is explained at page 364, they are equivalent to asserting that the action of pumps drawing water from a river among the hills is influenced by tides, or pumps operating at its mouth in the sea.

If the fluids in animal vessels had no weight, it is true, that in absorption, an external atmospheric pressure of fifteen pounds per inch might force new matter into a receiving orifice, at the instant during inspiration, when the opposing pressure in the chest, at the other ends of the

vessels, were half an ounce per inch less,—there would be no physical absurdity in supposing this, although there are physiological facts that disprove it—but when we reflect, that in all vessels under the level of the heart, the weight of the contained fluids causes an additional outward pressure of about half an ounce troy for every perpendicular inch of fluid column, making an excess of outward pressure at the toes, for instance, even at the most favourable time for absorption, of about two pounds per inch; we see that absorption must be a strong *action of life*, able to overcome a great excess of mechanical resistance, instead of a passive phenomenon obeying an excess of mechanical force. If a mere balance of pressures acted at the orifices, as Dr. B. supposes, the blood and other fluids would be constantly oozing out from all orifices below the heart, as blood really does from an artificial opening, with force that would fill a tube reaching as high as the heart. It would be good news for proprietors of mines, and other persons having to raise water, if by taking off an ounce or two per inch of the atmospheric pressure at the top of a full pipe, the atmospheric pressure continuing elsewhere would then force water in at openings below and cause an upward current:—but in truth, to make the atmosphere efficient below, powerful steam-engines or other means must be used to take off a pressure above, of at least half an ounce per square inch, for every inch in height which the water has to rise.

Another erroneous conception of atmospheric pressure, akin to that which we have been consi-

dering, is expressed in the following reasoning on the progress of blood in the veins. "The atmosphere presses 15 lbs. per square inch on all things; the blood therefore, in a vein which has 20 inches of surface, is pressed upon, through the flesh, with a force of 20 times 15, or 300 lbs., while a cross section of the vein near the heart would measure less than one inch. The blood, therefore, is always running towards the heart, to escape from a powerful excess of atmospheric pressure."—This paradox is solved by the law of fluid pressure, explained at page 262. The same reasoning would prove that an eel-skin suspended by its lip, and filled with water, when exposed to the pressure of the atmosphere, should quickly be emptied; and nearly the same would prove that a long sharp wedge thrown into water, should be always moving in a direction away from its point; and that a ship formed like the wedge, should make quick speed across the sea without either oar or sail.

A knowledge of the facts detailed under the three heads of *arteries*, *capillaries*, and *veins*, prepares us for the discussion of the following subjects.

### *The force of the Heart.*

The arterial tension of four pounds to the square inch, marked by its supporting in a tube connected with the arteries, a column of blood eight feet high (*see page 549*), is produced by the action of the heart; but as the heart, while injecting the blood against this resistance, has moreover to overcome the *inertia* both of the quantity injected, and



of the mass in the great artery, first moved by the injection, as also the resisting *elasticity* of the vessel which yields to momentary increase of pressure, the heart must act with a force exceeding four pounds on the inch. And as the left ventricle of the human heart, when distended, has about ten square inches of internal surface, the whole force exerted by it is a matter of simple calculation. It is remarkable, as there is this easy means of solving the question, that the accurate Majendie, in his recent elements of physiology, should speak of it as undetermined; and should cite, as the best approximation, an estimate made from the obscure circumstance of a loaded foot shaking in unison with the pulse, when suspended in the cross-legged sitting attitude.

Some physiologists have expressed surprise that the force of the heart should be so great as it is, remarking that much less would have sufficed to propel the blood to the most distant capillaries; but they did not reflect that the heart, besides carrying on the general circulation, has to force blood into those parts of the flesh which in the various positions of sitting, lying, standing, &c., are for the time compressed by the whole weight of the body; for that, if it were not strong enough for this purpose, either the compressed parts, deprived of their nourishment, would quickly die, or the person, obliged to be every moment changing position, could obtain no lengthened repose. In illustration of this point, we may advert to the frequent occurrence, in diseases where the power of the heart is for the time weakened,

of sloughings, or bed-sores in the bearing parts, causing many cases of illness to terminate fatally which would otherwise soon have terminated in health.—The author of this work has had great satisfaction in suggesting a means of entirely preventing such deplorable terminations, namely, that which he is now about to describe under the title of

*The HYDROSTATIC BED for Invalids.*

In many of the diseases which afflict humanity, more than half of the suffering and danger is not really a part of the disease, but the effect or consequence of the confinement to which the patient is subjected. Thus a fracture of the bone of the arm is as serious a local injury as a fracture of one of the bones of the leg ; but the former leaves the patient free to go about and amuse himself, or attend to business as he wills, and to eat and drink as usual—in fact, hardly renders him an invalid ; while the latter imprisons the patient closely upon his bed, and brings upon him, first, the irksomeness of the continued position, and then the pains of the unequal pressures borne by the parts on which the body rests. These, in many cases of confinement, disturb the sleep and the appetite, and excite fever, or such constitutional irritation as much to retard the cure of the original disease, and not unfrequently to produce new and more serious disease. That complete inaction should prove hurtful to the animal system, may by all be at once conceived ; the operation of the continued local pressures will be understood from the fol-

lowing statements. The health, and even life, of every part of the animal body, depends on the sufficient circulation through it of fresh blood, driven in by the force of the heart. Now when a man is sitting or lying, the parts of his flesh compressed by the weight of the body, do not receive the blood so readily as at other times ; and if from any cause the action of his heart has become weak, the interruption will both follow more quickly and be more complete. A peculiar uneasiness soon arises where the circulation is thus obstructed, impelling the person to change of position ; and a healthy person changes as regularly, and with as little reflexion, as he winks to wipe and moisten his eye-balls. A person weakened by disease, however, while he generally feels the uneasiness sooner, as explained above, and therefore becomes what is called restless, makes the changes with much fatigue ; and should the sensations after a time become indistinct, as in the delirium of fever, in palsy, &c., or should the patient have become too weak to obey the sensation, the compressed parts are kept so long without their natural supply of blood that they lose their vitality, and become what are called sloughs or mortified parts. These have afterwards to be thrown off, if the patient survive, by the process of ulceration, and they leave deep holes, requiring to be filled up by new flesh during a tedious convalescence. Many a fever, after a favourable crisis, has terminated fatally from this occurrence of sloughing on the back or sacrum ; and the same termination is common in lingering consumptions, palsies, spine dis-

cases, &c., and generally in diseases which confine the patients long to bed.

It is to mitigate all, and entirely to prevent some of the evils attendant on the necessity of remaining in a reclining posture, that the hydrostatic bed is intended. It was first used under the following circumstances.

A lady after her confinement, which occurred prematurely, and when her child had been for some time dead, passed through a combination and succession of low fever, jaundice, and slight phlegmasia dolens of one leg. In her state of extreme depression of strength and of sensibility, she rested too long in one posture, and the parts of the body on which she had rested all suffered: a slough formed on the sacrum, another on the heel; and in the left hip, on which she had lain much, inflammation began, which terminated in abscess. These evils occurred while she was using preparations of bark, and other means, to invigorate the circulation, and while her ease and comfort were watched over by the affectionate assiduity of her mother, with numerous attendants. After the occurrence, she was placed upon the bed contrived for invalids by Mr. Earle, furnished for this case with pillows of down and of air of various sizes, and out of its mattress portions were cut opposite to the sloughing parts; and Mr. Earle himself soon afforded his valuable aid. Such, however was the reduction of the powers of life, that in spite of all endeavours, the mischief advanced, and about a week later, during one night, the chief slough on the back was much enlarged, another



had formed near it, and a new abscess was proceeding in the right hip. An air pillow had pressed where these sloughs appeared. The patient was at that time so weak that she generally fainted when her wounds were dressed; she was passing days and nights of uninterrupted suffering, and as all known means seemed insufficient to relieve her, her life was in imminent danger.

Under these circumstances, the idea of the hydrostatic bed occurred to me. Even the pressure of an air-pillow had killed her flesh; and it was evident that persons in such a condition could not be saved unless they could be supported without sensible inequality of pressure. I then reflected, that the support of water to a floating body is so uniformly diffused, that every thousandth of an inch of the inferior surface has, as it were, its own separate liquid pillar, and no one part bears the load of its neighbour—that a person resting in a bath is nearly thus supported—that this patient might be laid upon the surface of a bath over which a large sheet of the water-proof India-rubber cloth were previously thrown, she being rendered sufficiently buoyant by a soft mattress placed beneath her—thus would she repose on the face of the water, like a swan on its plumage, without sensible pressure anywhere, and almost as if the weight of her body were annihilated. The pressure of the atmosphere on our bodies is of fifteen pounds per square inch of its surface, but because uniformly diffused, is not felt. The pressure of a water bath of depth to cover the body, is less than half a pound per inch, even on the

under side where it is greatest, and is similarly unperceived. A bed such as then planned was immediately made. A trough of convenient dimensions (6 feet long, 2 feet 8 inches wide, and 11 inches deep, are good common dimensions) was lined with metal, to make it water-tight; it was about half filled with water, and over it was thrown a sheet of the India-rubber cloth as large as would be a complete lining to it if empty. Of this sheet the edges, touched with a spirit varnish to prevent the water creeping round by capillary attraction, were afterwards secured in a water-tight manner all round to the upper border or top of the trough, shutting in the water as closely as if it had been in bottles, the only entrance left being through an opening at one corner, which could be perfectly closed. Upon this beautiful dry sheet a suitable mattress was laid, and constituted a bed ready to receive its pillow and bedclothes, and not distinguishable from a common bed but by its most surpassing softness or yielding. The bed was carried to the patient's house, and she was laid upon it; she was instantly relieved in a remarkable degree: sweet sleep came to her; she awoke refreshed; she passed the next night much better than usual; and on the following day, Mr. Earle found that all the sores had assumed a healthy appearance: the healing from that time went on rapidly, and no new sloughs were formed. When the patient was first laid upon the bed, her mother asked her where the down pillows, which she before had used, were to be placed; to which she answered, that she knew not, for that she felt

no pain to direct: in fact, she needed them no more.

It may be here recalled to mind, that the human body is nearly of the specific gravity of water, or of the weight of its bulk of water, and therefore, as is known to swimmers, is just suspended or upheld in water without exertion, when the swimmer rests tranquilly on his back with his face upwards. He then displaces water equal to his own body in weight as well as in bulk, and is supported as the displaced water would have been. If his body be two and a-half cubical feet in bulk (a common size), he will just displace two and a-half cubic feet of water, equal in weight to his body. If, however, instead of displacing the water with his mere body, he choose to have something around or under him which is bulky with little weight, as the mattress of the bed above described, then, after his weight has forced two cubical feet of that under the level of the water around, he will float with four-fifths of his body above the level, and will sink much less into his floating mattress than a person sinks in an ordinary feather-bed. It thus appears that by choosing a certain thickness of mattress, and if unusual positions are required, by having different thickness in different parts, or by placing a bulk of folded blanket or of pillow over or under the mattress in certain situations, any desired position of the body may be easily obtained. If the water be about six inches deep, which in general will suffice, the person standing upon any part of the bed, or sitting with the knees raised, will cause the part of the mattress

on which he rests gently to touch the bottom, because a narrow end of the body cannot displace water equal to the bulk of the whole, but even then the person is as if standing or sitting on a soft sofa. If it be desired to prevent the mattress, when used as a seat, from touching the bottom, the object may be attained by having under its middle a broad band or strap fixed to one edge of the trough, and connected with the other by buttons or otherwise, so as to be tightened to allow the mattress to descend just so far, and no farther.

This bed is a warm bed, owing to water being nearly an absolute non-conductor of heat from above downwards, and owing to its allowing no passage of cold air from below. From this last fact, however, less of the perspiration, sensible and insensible, is carried off by the air than in a common bed, and unless the patient can leave the bed daily to let it be aired like a common bed, there will be a necessity for ventilation to prevent the perspiration from being condensed on the water-sheet below. This ventilation is perfectly obtained by placing under the mattress, arranged like the bars of a gridiron, small flexible tubes of tinned wire, wound spirally, with their ends open to the atmosphere, either directly or through two larger tubes crossing and connecting their extremities near the ends of the mattress, and then issuing at the corners of the bed from under the clothes. This bed is in itself as dry as a bed can be, for the India-rubber cloth (of which bottles can be made) is quite impermeable to water, and the maker is now preparing cloth



expressly for this purpose. Then, as Sir Humphrey Davy recommended that his safety lamp should be double, some persons may prefer a double sheet, to obviate the possibility of accident. Unlike any other bed that ever was contrived, it allows the patient, when capable of only feeble efforts, to change his position, almost like a person swimming, and so, to take a degree of exercise, affording the kind of relief which in constrained positions is obtained by occasional stretching, or which an invalid seeks by driving out in a soft-sprung carriage. It exceedingly facilitates turning for the purpose of dressing wounds, for by raising one side of the mattress or depressing the other, or merely by the patient's extending a limb to one side, he is gently rolled over, nearly as if he were simply suspended in water; and it is possible even to dress wounds, apply poultices, or place vessels under any part of the body, without moving the body at all; for there are some inches of yielding water under the body, and the elastic mattress may at any part be pushed down, leaving vacant space there, without the support being lessened for the other parts. Then, with all the advantages which other invalid beds possess, and with those which are entirely its own, it may yet be made so cheaply, that even in hospitals, where economy must prevail, it may at once be adopted for many of the bed-ridden. Mr. Earle, within a few days of seeing the first one, had others made for patients in St. Bartholomew's Hospital, and has been as much pleased with the results of them as of the first. The bed has since been intro-

duced into St. George's Hospital by Mr. Keate, and elsewhere.—The author has now seen enough of the effects of this bed to make him feel it a duty at once to publish a notice of it. With it evidently, the fatal termination called sloughing, now so common, of fevers, and other diseases, need never occur again. And not only will it prevent that termination, but by alleviating the distress through the earlier stages, it may prevent many cases from even reaching the degree of danger. Then it is peculiarly applicable to cases of fractured bones, and other surgical injuries; to palsies, diseases of the hip joint, and spine; and universally, where persons are obliged to pass much time in bed. And in all cases of curvature of the spine, either actually existing or threatened, it affords a means of laying a patient in any desired position, and with any degree of pressure incessantly urging any part of the spine back to its place. If used without the mattress, it becomes a warm or a cold bath, not allowing the body however to be touched by the water; and in India, it might be made a cool bed for persons sick or sound, during the heats which there prevent sleep and endanger health. There are numerous other professional adaptations and modifications of it, which will readily occur to practitioners sufficiently versed in the department of natural philosophy (hydrostatics) to which it belongs. Before reflection a person might suppose a resemblance between it and an air-bed or pillow, calling this a water-bed or pillow; but the principles of the two are perfectly distinct or opposite. An air pillow

supports by the *tension of the surface* which encloses the air, and is therefore like a hammock or the tight sacking under the straw mattress of a common bed, and really is a hard pillow; but in the hydrostatic bed, there is no tense surface or web at all: the patient is floating upon the water, on which a loose sheet is lying, merely to keep the mattress dry, and every point of his body is supported by the water immediately beneath it. To recall the difference here described, and which is of great importance, the bed is better described by the appellations of *hydrostatic bed* or *floating bed* than of *water-bed*.

The author has given no exclusive right or privilege to any person to make this bed. He has hitherto employed the carpenter nearest to him, Mr. Smith, 253, Tottenham-court Road, at the back of Bedford Square; Mackintosh and Co., 58, Charing Cross, the manufacturers of the cloth; and Mr. Williams, 25, Cleveland Street, Fitzroy Square; but any carpenter or upholsterer may learn to supply them, and he gives free permission to all. He hopes, for the sake of the poor, that a trough without metallic lining, and with a cheaper water-proof cloth, may be found to answer satisfactorily.

The principle of the hydrostatic bed is applicable, also to couches for invalids, and with certain considerable modifications, to the construction also of chairs; and there are other means than the water-proof sheet of adopting the hydrostatic principle for all—but the subject has already occupied its full share of this volume.

The preceding paragraphs are intended as much to direct in the choice and use of common beds for the sick, as to announce and describe the hydrotatic bed for the cases in which it may be required. At present the medical attendant generally leaves whatever regards the bed to the judgment of friends or nurses ; but evidently, he who has been led to reflect how much the course and event of a malady may depend on the patient's being supported, so that no pain shall arise from local pressure, and as little muscular weariness as possible from constrained position, will deem the bed-management worthy of his own attention, and will be able more judiciously both to choose and to use beds. There is a bed constructed of spiral springs, which may be made so as to diffuse the support more equably than any except the hydrotatic bed ; and had professional men generally been acquainted with it, it would have been more used than it is, and would have received various modifications, of which it is susceptible, for medical purposes. It has long been known, chiefly however as a mechanical curiosity, or an object of luxury, and was introduced into this country about seventy years ago by Mr. Merlin ; but it has been so little known, that a few years ago an English tradesman thought he might appropriate the manufacture by taking a patent for it. It is now made by upholsterers generally, and the same principle is applied in the construction of sofas, chairs, and carriage cushions.



*The velocity of the circulating Blood.*

This has been much over-rated. 1st. By assuming that the ventricles of the heart are both completely filled from the auricles and emptied towards the arteries at each pulsation :—an assumption disproved by inspection of the exposed heart of a living body, and by the fact of the valves between the auricles and ventricles not closing so perfectly as quite to prevent regurgitation. 2d. By supposing the issue of blood from a wounded artery or vein to be the measure of the usual velocity. Now it would be as reasonable to suppose the issue of water from a wounded pipe connected with any reservoir to be the measure of a continued current in that pipe, although in truth, the issue would be the same even if the water in the pipe were usually at rest. 3d. By supposing the *frequency* of the pulse to be a measure. Now we know, that in diseases of debility, and in animals bleeding to death, the pulse usually becomes more frequent as it becomes more feeble, and as there is less blood moving : the heart, *viz.*, very partially discharging its contents at each contraction. 4th, and lastly. By supposing the *strength* of the pulse to be the measure. Now we find that the pulse in an artery just tied, and in which, consequently, there is no current at all, is scarcely weaker than in an open artery. The common fact of a person's feet remaining stone-cold for hours, although the arteries leading to them pulsate nearly as usual, is a proof that exceedingly little blood is passing through the capillaries at the time, and that the strength of the pulse,

therefore, is no measure of the speed of the blood.

The ventricles of the heart appear, under common circumstances, to throw out about an ounce and a-half of blood at every contraction—or about seven pounds per minute. Now if the body contain about twenty pounds altogether, as seems to be the case, the whole would circulate twenty times in an hour. This would give an average velocity of about eight inches per second in the aorta, but gradually less in the smaller arteries, because whenever a vascular channel subdivides, the branches taken collectively have considerably greater area than the trunk from which they arise, and the current diminishes in a corresponding proportion,—just as the speed of a river is always less in the parts of the channel which are deeper and broader. The velocity in the extreme capillaries is found to be often less than one inch per minute. In the veins, the blood must move more slowly than in corresponding arteries, in proportion as the veins are more capacious than the arteries.

### *The Pulse.*

The opinion which the ancients held, that the arteries contained *vital spirits* or *air* and not *blood*, rendered the pulse, to them, a very mysterious phenomenon; and many curious hypotheses were framed to explain it. These it would now be unprofitable to detail. Even Harvey's grand discovery of the circulation, however, has not rendered the subject so simple as might have been

anticipated. The following opinions now exist, or have lately existed, with respect to the pulse.

1st. The great majority of physiologists have believed that a tumefaction is produced in the aorta by each jet of blood from the heart, and spreads afterwards as a wave into all the arterial branches. 2d. Many have supposed an extensive contractile action of the arteries themselves, corresponding to that of the heart. 3d. Bichât, unable by any means to detect the slightest change of diameter in the arteries during pulsation, but perceiving that in many situations they were at the time somewhat lengthened, so that straight portions became bent, and portions originally bent, were bent still more, held that this locomotion, or changing of place in the arteries, was the cause. 4th. Others have supposed the impulse of the heart's contraction to be transmitted through the fluid blood, somewhat as sound is transmitted through bodies generally, or as a blow struck on one end of a log of wood, is felt distinctly by a hand applied to the other, although there be no visible locomotion. 5th. Dr. Young, in the paper in the Philosophical Transactions already alluded to, has shewn that a sudden rush forward of the blood in the artery, such as might be produced by injection at one end of a rigid tube, would be felt by a finger applied to the artery, quite as distinctly as a tumefaction; and he deems this occurrence to be a chief cause of the pulse. Dr. Parry, in his work on the pulse, points to this almost exclusively as the cause.

Now the truth is, that the pulse in the living

body does not depend exclusively upon any one of the particulars just noticed, but has all of them as elements; and its fluctuations and varieties depend upon the proportions in which these elements are combined. We shall review them again to prove this.

1st. At each jet of blood thrown into the aorta, a tumefaction or wave *must* spread from the heart to the extremities; for it is evident, that if blood be at all pushed into the arterial system, it either must dilate it, or cause an equal quantity to be expelled at the same instant from the distant extremities: now as the passage of blood through the capillaries appears perfectly uniform, there must be an intermediate dilatation. Dr. Parry and others should not have denied this dilatation because they could not see it: for even if its advancing front were more considerable than it is, it passes with such velocity that, like a cannon ball crossing before the face, it would not be perceived.

2d. Contraction of the arterial coats certainly does not take place in the manner and to the extent supposed by some, who have spoken of it as resembling the contraction of the heart itself, and as what might be a substitute for the action of the heart in propelling the blood; but, as shewn at page 554, the rigidity of tube which in all degrees of arterial dilatation causes the pulse to be transmitted so quickly, can depend on nothing but a contractile action of the fibres. There are some reasons for doubting whether this rigidity may not increase at the moment of the pulse.

3d. Unless the arterial tubes were absolutely



inelastic, which they are far from being, they *must* be lengthened a little by a sudden injection of blood, and therefore, at all the curvatures particularly, there *must* be a degree of the locomotion described by Bichât, often sensible to a finger applied.

4th. That a tangible shock is conveyed through a fluid without any apparent accumulation of the fluid or change of velocity, and much in the manner of sound, is proved by the facts, that we may discover the working of a water-pump at very great distances, through iron pipes connected with it, and even through elastic pipes of leather, as those of a common fire-engine, from which the water is spouting, nevertheless, in a uniform stream. The pulse in a tied artery, in which there is no current or rushing wave, must be chiefly from this cause, and from the locomotion of the artery.

5th. That any additional quantity of fluid injected into elastic vessels already full, *must* spread all over with a *forward rush*, affecting the finger of an examiner as described above, is also most certain. As the heart, however, often beats without discharging much of its blood, and as in many arteries, from inaction of the capillaries, or pressure, the blood for a time makes little or no progress, while the pulse, however, remains very distinct, the pulse in such cases must be produced independently of the forward rush. An animal intestine prepared, and filled with water or air, and laid upon a table—or a full vein in the living body, carries a rapid and distinct pulse to a great distance when gently tapped by the finger. The cause of

the sensation, then, cannot be the simple forward *rush* without tumefaction, described by Dr. Young and Dr. Parry.

In whatever proportions these particulars combine to form the pulse, its force will be proportioned to the size of the artery. Hence as an artery leading to an inflamed part becomes of greater calibre, its pulse also becomes stronger.

It is a remark respecting the pulse, appearing to the author worthy of deep consideration, that if the purpose of the heart and arteries were merely the propulsion and conveyance of the blood, their structure and action would form most signal deviations from the ascertained rules of fitness in mechanics. In machines of human contrivance, it is one of the most important maxims "to avoid shocks, or jerking motions;" and in former parts of this work, we have described fly-wheels, air-vessels, springs, &c. as means of accomplishing this object, and thereby of preventing the tearing and straining of parts which would else happen. In the human body, also, we have had to describe the admirable elasticity of the spine, of the arch of the foot, of the cartilages of joints, &c. as contrivances answering the same ends; and to remark that, in other cavities than the heart, which are alternately filled and emptied like it, as the stomach, bladder, uterus, &c., there is a smooth and gradual action. The heart alone is the rugged anomaly which, from before birth unto the dying moment, throbs unceasingly, and sends the bounding pulse of life to every part; and which moreover, instead of being secured and tied down to

its place, is attached at the extremity of the aorta, like a weight at the end of an elastic branch of a tree, and every time that it fills the aorta, is thrown with violence, by the consequent sudden tendency of that vessel to become straighter, against the ribs, in the place where the hand applied, feels it so distinctly beating.

Now one use of the pulsation of the heart probably is, by the *agitation* and *churning* which the blood suffers in passing through it, to keep in complete mixture all the heterogeneous parts of the blood, which so readily separate when left to repose:—but this cannot be the only use, for the object might have been more simply attained; and we may conclude that the phenomenon has relation to some important law of life still hidden from us. The cause commonly assigned for the heart's contraction is the peculiar stimulus of the blood; yet if we reflect that the heart will beat after removal from the body, and when it contains only air, and that during life it beats with extraordinary regularity, whether the state of the circulation allow it to empty itself at each beat or not, we perceive that the cause is more obscure. We cannot contemplate this subject attentively without perceiving a strong analogy between the action of the heart and some electrical phenomena in which there are successive accumulations and exhaustions of power; and, recollecting the important relations which late researches have shewn to exist between electricity and certain other actions of life, the inquiry becomes very interesting. Galvanism can excite the muscles to their usual actions; it powerfully affects

the secretions and the digestive function ; and the breathing in asthma : strong animal passion seems to produce electrical excitement : and certain animals have the faculty of stunning their enemies by an electrical discharge. The pulse, then, in its sudden, strong, and regular recurrence, may be a kindred phenomenon. In this view, there would be less difficulty in supposing a momentary stiffening or slight contraction of the whole arterial system, such as the sudden rising of the mesenteric arterial tree so readily suggests : if there be such, however, it is still closely connected with, and proportioned to, the action of the heart ; for it occurs only with that action, it indicates any disturbance in the action, and as death approaches, it ceases in the remote extremities first.

The preceding considerations exhibit the pulse as a complex subject, and one on which professional opinions are not yet settled. By shewing its close relation to the powers of life, they also prove it to be an object of high importance to the medical practitioner. This last truth has scarcely been questioned but by persons either utterly uninformed or singularly deficient in the power of tactile discernment ; yet, because no simple and good analysis of the pulse, and detail of its relation to morbid states, has been made and published, the degrees of skill acquired by individual practitioners with respect to it are very various, and in a great measure accidental. Some practitioners try the pulse merely for form's sake, because patients expect it ; many examine it only to count its frequency ; but others read in it, with confidence,



much of the history and probabilities of the disorder, and decide on the treatment accordingly. Few who have attended to the subject at all, can confound the pulses of such diseases, as acute rheumatism, gastric inflammation, the fits of ague, &c. The author remembers to have conversed with a Chinese practitioner who had only the scanty medical information of his countrymen, but who judged by the pulse with singular penetration.

The changing circumstances in the state of the circulatory system, connected with health and disease, and discoverable by a finger watching the pulse, seem to be chiefly the following; and the epithets added in italics, are those which seem best to indicate the sensations perceived. The artery at the wrist is that generally chosen for examination, because it is not like others imbedded in soft parts, having only the skin over it, and nothing between it and the bone below.

1st. The number of the contractions of the heart in a given time, and the regularity of their recurrence.—Pulse, *frequent, slow, intermittent, equal, regular, of varying force.*

2d. The degree of the heart's contraction, or the quantity of blood ejected at each time; and the corresponding state of the capillaries as to the quantity of blood passing through them.—Pulse, *full, long, labouring, bounding, feeble.*

3d. The force of the heart's action, with the correspondent arterial tension or rigidity.—Pulse, *hard, sharp, strong, wiry, weak, soft, yielding.*

4th. The suddenness of the individual contrac-

tions of the heart, and the rigidity of the vessels in conveying the shock.—Pulse, *quick, tardy*.

5th. The size of the artery for the time, whether larger or smaller than usual.—Pulse, *large, small*.

Superficial as is this sketch, it may shew that a good treatise on the subject of the pulse, as connected with disease, is yet a desideratum in medicine. The sort of empirical, but useful tact which many persons acquire, is not fitted to satisfy the physician which reasons deeply, and whose mind should have always present to it the various constituents of the pulse, and all the important circumstances of health or disease related to its indications. The laboured treatises of *Solano, Bordeu, Boerhaave*, &c. may treat of what were clear ideas to their authors, but by not referring to the physical causes of many varieties, they become so obscure to others, that many of the divisions and denominations appear altogether fanciful. Dr. Young's excellent paper in the *Philosophical Transactions* details important facts, as far as it goes, but it was not intended to point out all the pathological relations. Dr. Y., guided by general principles, asserted a progressive motion of the pulse, while other authorities were holding it to be quite simultaneous over the whole system. He might have mentioned in proof, that careful examination can practically detect a succession of beats at different distances, particularly at the four stations; 1st. of the heart; 2d. in the lip; 3d. at the wrist; 4th. at the ankle :—but the interval of time, even between the extremes, being only a small part of a second, persons will often fail to make their first

experiment satisfactorily. Dr. Parry's treatise on the pulse, which is the last one of note, although having excellencies, errs—in attributing the phenomenon to one cause too exclusively—in denying arterial dilatation, because it was not discovered by his mode of searching for it,—in supposing that a liquid column in an elastic tube can be made to advance like a solid rod, or a line of billiard balls. The too common neglect of mechanical philosophy by medical men, is signally proved, by our finding in works of authority, published at the present day, such statements as that the arterial pulse may be more frequent or less frequent than the beatings of the heart. *Dr. Good (Study of Medicine)* says, that there may be various frequency of pulse in various parts of the body at the same time : *Richerand (Physiologie)* says, the pulse is more frequent in the artery leading to a whitlow than at the same time elsewhere; and many practitioners share these notions. What a satire on the medical profession is this disagreement, on a point which to common observers seems above all others to occupy the attention of the attendant on the sick!

Having now explained the circulation of the blood in general, we proceed to consider some cases where mechanical circumstances modify it.

#### *Circulation in the Head.*

The head may be considered as an air-tight vessel or cavity of bone, containing chiefly brain and blood, and having openings occupied by blood-vessels leading to and from the heart. The

atmospheric pressure, therefore, always keeps the head full, as it keeps the top of a syphon full; and because the substance of the brain itself does not, more than water, sensibly change in bulk by any ordinary degree of pressure, there must always be the same quantity of blood in the head, how much soever the quantity may vary in the body generally. Regard to this important truth, a knowledge of which has followed the discovery of the true nature of atmospheric pressure, enables us to explain many hitherto obscure facts, both in health and in disease;—as the following instances will shew.

If from any cause the arteries in the head become too full of blood, in the same proportion the veins must become too empty; or, if the veins be too full, the arteries must be too empty; and in either case the circulation in the head will be in a corresponding degree impeded, because when one part of a channel is narrowed or diminished, the current throughout the whole is slackened. Now as insensibility supervenes when the supply of fresh blood to the brain is interrupted, and death follows if the interruption continue long, it seems evident that in many of the cases of apoplexy, where, on inspection, there is found nothing but a fulness of the arterial or of the venous system of the head, death has happened merely because the circulation was arrested in this way. In other parts of the body, not circumstanced like the brain, an excess of blood in one set of vessels may happen without inducing deficiency in another, and therefore with perfect impunity to the individual.



Simple increase of pressure produced by the blood on the brain, provided the proper balance exist between the quantity in veins and arteries, has no injurious effect. This is proved by the safe descent of a person in the diving-bell, where at thirty-four feet under the surface of the water the body is bearing an additional pressure of fifteen pounds on the square inch (see page 334), which pressure through the blood-vessels affects the brain as much as any other part.—On the other hand, when a man climbs a mountain, or is lifted in a balloon, the brain is less pressed than usual; but the proper balance in artery and vein being maintained, no inconvenience is felt. The inhabitants of some of the vallies among the Andes are as far above the sea as they would be at the top of Mont Blanc, where the atmosphere presses only half as much as on the sea-shore, but they enjoy good health.

As the box of the cranium encloses the brain so as to leave no vacant space, it is evident, that when the heart injects blood with unusual violence, the strain at first is borne chiefly by the cranium, and not by the coats of the blood-vessels. Hence the arteries of the brain need not be, and are not nearly so strong as those of other parts of the body.

The veins of the brain are also peculiar. Common veins in the head would, for the reason above given, collapse by any sudden tension of the arteries there, and if they did, insensibility or death would ensue, on account of the consequent stoppage of the circulation. The chief channels,

therefore, for the reflux blood, instead of being common compressible veins, are what have been called *sinuses*, or grooves in the bone itself, with exceedingly strong membranous coverings, supported so, that the channels become in strength, and as to maintenance of their capacity, little inferior to complete channels of bone. This singular deviation in the structure of the cerebral veins from what is found elsewhere, and without which deviation animal existence could not be continued, is one of those particulars which powerfully affect the contemplative mind, as proofs of the designing intelligence which has planned this glorious universe.

From not adverting sufficiently to the fact now explained, of the cranium being a vessel always full, and which will hold only a certain quantity, misconception has prevailed among medical men with respect to many of the affections of the brain.

It has been said, for instance, that the substance of the brain cannot bear pressure with impunity, for that stupor immediately follows pressure, however produced. Now the truth is, that pressure produces stupor only when it interferes with the circulation. In wounds with loss of a large piece of the cranium, the brain will bear very rough handling, because if compressed at one part, it may bulge in another, and leave the circulation free; but if the wound be small, pressure made through it instantly affects the whole brain, and the blood is prevented from entering from the heart.—Let one reflect for an instant on what happens to the foetal head during parturition—how often

it escapes elongated and bent, almost as if it were of soft clay—yet the child lives and thrives, and the natural form is soon recovered. The reason is, that the foetal skull is soft, and pressure in one part is compensated for by a bulging or extension in another, and the blood is not expelled.

Water in the head, again, is said to kill by this fatal pressure on the tender brain: but, in reality, it kills by keeping out the blood, and so mechanically arresting the circulation. Accordingly we see, that where the *fontanelle* still remains open, or where the *sutures* or joinings of the skull will yield, water may accumulate to a great degree without causing much disturbance.

A tumour in the brain, which would be of no consequence if the brain were unconfined, soon becomes fatal by occupying room in the skull, and to the extent of its size excluding or checking the supply of blood.

If the substance of the brain at all increase and diminish in bulk, as muscles, &c., under certain circumstances, do, in the body below, all such changes must produce a considerable effect on the cerebral circulation and functions.

#### *Effects of position on the circulation.*

While a man is in a standing attitude, the heart and arteries have to send the blood up to the head against gravity: but in the horizontal position, the blood if equally propelled, must arrive with greater force, because gravity then does not resist. Hence head-ache, or other symptom arising from fulness of blood in the arteries of the head, is often re-

lived by the upright position, and is increased by lying down.

Many people who have had a slight degree of tooth-ache during the day, find it intolerable when they lie down at night, and are relieved again by rising and walking about. Commonly they suppose that it is the cold of the night which then lulls the pain; but it is in fact the change of position. The author knew a lady who was obliged to sleep for months in the sitting posture, because she had a *tic douloureux* in the face whenever she lay down; and another who was under the same necessity for a considerable period after an inflammatory affection of the brain, because if her head fell low during sleep she was immediately assailed by a terrific dream of swords driven into the brain.

Delirium in fever is sometimes checked at once by elevating the head. On account of the great relief thus obtained, some continental practitioners had proposed to support the patients occasionally in an upright posture.

Apoplexy has often been brought on by a man bending his head down in the act of tying his shoe, or of pulling on his boot.

Children and professed tumblers being much in the habit of placing their bodies in all positions, feel no inconvenience from having the head downwards; apparently, because arteries and veins usually become strong enough to bear the pressure to which they are habitually exposed; but to many old people, accustomed to keep the head always up, the attempt would be fatal.

Ulcers on the legs are often obstinate and will



bleed, because the veins about them are too weak to support the lofty columns of blood above. Hence the frequent counsel given in such cases to keep the feet raised upon a chair, and the utility of certain modes of bandaging.

Many inflammations of the legs and feet become exceedingly painful when the limbs are in a hanging position, and the pain is relieved by laying them horizontally.

Many anasarcaous or dropsical affections of the legs increase towards night, because during the dependent position of the legs through the day, the absorbents have not power to lift the fluid. The swelling disappears again before morning.

When the heart has to send blood upwards, it requires to act more strongly than when the body is horizontal, and the pulse increases five or six beats in the minute: hence the common rule to make a patient with hemorrhage lie in the horizontal position, that the heart may become tranquil, and allow the bleeding to cease.

*Fainting from diminished arterial tension.*

*Fainting*, which is a temporary cessation of the action of the heart, and hence, as explained above, of the action of the brain for want of blood, is produced by several causes, and among others, by any occurrence which renders the blood-vessels about the heart suddenly less full or tense than usual. It would appear that the heart being accustomed, when it contracts, to a certain degree of resistance, has its action disturbed when the resistance is much diminished.

Thus hemorrhage, from any cause, by lessening the general tension of the sanguiferous system, often causes fainting. The state is relieved by lying down ; probably because the still remaining weaker action of the heart is sufficient to send blood to the head along a horizontal course, until the gradual contraction of the whole vascular system reproduces the tension necessary to perfect action. A small quantity of blood taken away *suddenly*, affects the circulation as much as a larger quantity taken *gradually*, apparently because a certain space of time is required for the gradual lessening of the vessels.

The operation of *tapping* for dropsy in the abdomen would often bring on fainting, but for the precaution of tightening a broad bandage upon the body as the water flows. The reason is, that the sudden removal of a large quantity of fluid which had been compressing all the abdominal vessels, and keeping them perhaps only half full of blood, allows them again suddenly to receive their natural quantity, and thus produces a relaxation of the other parts of the vascular system.

Sudden parturition often causes faintness for the same reasons.

Even rising up suddenly from a horizontal position will cause an approach to fainting in weak people, or in those who have been long bed-ridden : probably because the heart having for a time been accustomed to send blood only in a horizontal direction to the head, does not in an instant exert the additional power required to lift an upright column with equal force ;—besides that the blood

does not then return to the heart, by the veins, from the inferior parts of the body, so readily as before.

These various facts, now easily understood, form the reason of a rule which is a great modern improvement in the practice of the healing art, *viz.* in bleeding for the cure of inflammation, to take the blood away as *quickly* as possible. This subject deserves a little farther consideration.

A great proportion of dangerous diseases involve inflammation of some vital organ ; and inflammation consists chiefly, as already stated at page 561, of a gorging or over-distension of the capillary vessels in the part. The nature of the capillaries, again, is such (page 559), that when not maintained constantly full by the pressure of the heart behind them, they gradually, by their own action, empty themselves towards the veins,—as is seen in the disappearance of a local inflammation soon after the death of the person, or in the fact of the arteries being emptied of blood after breathing ceases, &c. Now ever since medicine deserved the name of an art, practitioners have accounted the lancet their sheet-anchor in inflammatory disease ; but it is only in late times, since the circulation of the blood was understood, that they have known the rationale of the remedy, *viz.* that it acts by diminishing vascular tension, and hence the action of the heart, and so allowing the small vessels to empty themselves by their own force, and to recover sufficiently to resist the return of an excessive load. It is still more lately that they have understood, how much more suddenly and

completely the disease is cured by abstraction of a small quantity of blood *so rapidly* as to produce fainting, than of a much larger quantity *so slowly* than only weakness follows. Judicious treatment now cures inflammation much more certainly and completely than was done formerly, yet with much smaller loss of the precious blood, and with less danger of those diseases of weakness, or of that complete breaking-up of the constitution, which often follow great depletion. To induce faintness, *large* openings are made into the veins—sometimes into two veins at once, and the patient is kept in the upright attitude. Often thus an inflamed eye, which was as red as scarlet before bleeding, in a few minutes is rendered nearly of the natural appearance; and intense internal inflammations, as of the brain, lungs, bowels, &c., which if neglected would be shortly fatal, are removed in the same manner. In all these cases the faintness seems to be almost equally efficacious, whether it happens after the loss of ten ounces of blood, or of fifty; or even, as sometimes occurs, when it happens without bleeding at all, after merely tying the arm in preparation.

Reflection upon these circumstances led the author to think that, in certain cases, the beneficial effects of blood-letting might be attainable by the simple means of *extensive dry cupping*, alluded to at page 365; that is to say, by diminishing the atmospherical pressure on a considerable part of the body, on the principle of the cupping-glass used very gently, and thus suddenly removing for a time from about the heart, a quantity of blood,



sufficient by its absence to produce faintness. The results of trial have been such as to give great interest to the inquiry, and the author's leisure will be devoted to the prosecution of it.—An air-tight case of copper or tin-plate, or of air-light cloth kept extended by hoops, being put upon a limb, and made close by a suitable collar tied at the same time round its mouth and the limb,—on part of the air being then extracted by a suitable syringe, in an instant the vessels all over the limb become gently distended with blood; and as the blood is suddenly taken from the centre of the body, faintness is produced, just as by bleeding from a vein. The excess of blood may be retained in the limb as long as desired, for the circulation is not impeded. To produce a powerful effect with a slight diminution of pressure, more than one limb must be operated upon at the same time.

An instrument resembling the contrivance now described, was proposed about twenty years ago by a non-professional person, as a means of drawing all sorts of diseases out of the body through the pores of the skin. He enclosed a leg in an air-tight case; he then admitted steam to heat the limb, and relax the pores of the skin, as he said, and then he worked an air-pump to draw out the disease. He called the engine the *air-pump vapour-bath*. In various cases where its true action was desirable, although not understood by the proposer, nor judiciously managed, it proved beneficial.

The operation of applying tourniquets or bandages round the limbs, so as to influence the trans-

mission of the blood, affects the action of the heart. It is said sometimes to have prevented the accession of ague. It is a means akin to those above described.

Because arteries are stronger and more tense than veins, a bandage may be put round a limb, tight enough to close the veins but not the arteries, and the limb will then swell beyond the ligature. By thus putting tight elastic bandages round all the limbs at once, and immersing them in warm water to favour the dilatation of their vessels, so much blood may be suddenly detained in them as to cause the person to faint. Such a means, therefore, might also be used remedially.

In the same way, a tight handkerchief, or stock round the neck, will often retain the venous blood in the head, and cause apoplexy.—Strong pressure made on the jugular veins, kills as certainly as if made on the windpipe.

When a *hernia* or other tumour is strangulated, it swells in the manner above described, and if not relieved, soon mortifies.

*Diffused pressure*, like that made by rolling a bandage round a whole limb, or by immersing the limb in fluid, must affect the circulation. The veins will be more compressed than the arteries, by reason of the distending force in them being less. Varicose veins, therefore, are usefully supported by a bandage or laced stocking. The reason why this manner of supporting assists so powerfully in the healing of ulcers on the legs, may be, that the support affects the capillaries and absorbents as well as the larger vessels.

Poultices, by their weight, produce a soft compression of the parts on which they are applied; and in certain cases, may benefit by mechanically squeezing the excess of blood out of weakened vessels.

The author has relieved the chronic inflammation of a sprained ankle, by ordering the foot and leg, covered with an oiled-silk stocking, to be enclosed in a boot strong enough to support the pressure of quicksilver, which was then poured into the boot. The effect is a pressure by the fluid metal on the weak vessels, of one pound to the square inch, for every two inches of the depth of metal above the part.—A height of four or five inches gives the relief expected. A much greater elevation would stop the circulation altogether. No bandage can press with uniformity approaching to this action of a fluid.

The effect of continued pressure, in removing tumours of various kinds, is explicable on the same principle. The author doubts not that in such cases, pressure properly managed, would prove a more valuable remedy than is at present generally supposed. The elastic steel half-hoop, with one cushion before and another behind, lately introduced for the relief of hernia, affords an admirable mode in certain cases, of producing a uniform pressure of the nature spoken of, and of any desired force.

When a man stands in a bath, with the water up to his chin, there is a pressure of the water upon his body, proportioned every where to the depth (see page 260). This pressure must pro-

duce a considerable effect on the blood-vessels of the lower parts of the body. We see in this that a bath must propel the blood from all other parts of the body, towards the cavity of the chest, which the pressure cannot reach. It is this effect which in part causes the feeling of thoracic oppression experienced by persons on first plunging into water, which feeling is usually attributed altogether to the cold.

The old practice of placing a patient in a pit, and surrounding his body with earth or sand, must have had a mechanical action of the kind now contemplated, in addition to any other influence.

*Transfusion of blood* from the vein of a healthy person, into that of one fainting or dying from hemorrhage, is an operation the converse of some of those mentioned above. It has been frequently performed with success. The cases to which it seems best fitted, are those of flooding after parturition, and of wounds; and there can be no doubt that many of the lives lost from these so frequently recurring causes, might be saved by its adoption. The blood to be injected is received into a vessel, as in common bleeding, from which vessel, by a fit syringe (to be described in a future page), it is transferred as it flows, into an opened vein of the patient. The admission of air with the blood would be fatal, and has therefore to be most carefully guarded against. The last interesting report upon this subject is that of Dr. Blundell, in his *Physiological Essays*.



## RESPIRATION AND VOICE.

*The doctrines of fluidity, illustrating and illustrated by the animal respiration and voice.*

As the motion of a windmill depends altogether on the breeze to which its vanes are exposed, so does the motion and the life of that most wonderful of structures, the animal body, depend on the supply of air for its breathing. If this supply be withheld but for a few moments, painful convulsions ensue; and if for a still longer period, the body, however perfect and beautiful, is made a lifeless corpse, soon to putrefy and be decomposed.

The mechanical nature of air, as to its lightness, elasticity, &c., and the fact of its forming an ocean around the earth of about fifty miles high, are now well understood, and have been fully explained under *Pneumatics*; but the precise nature of its life-sustaining action has yet to be elucidated by further research of chemists and physiologists. Thus far, however, we know—that the ingredient called *oxygen*, constituting a fifth of the atmosphere, is the most essential part—that air, by being breathed once, is rendered unfit for further respiration at the time—and that a man requires about a gallon per minute. The enterprising Mr. Spalding, who introduced the use of the diving-bell, descended for the last time with a companion on the coast of Ireland, when, owing to the signal cord becoming entangled round the great rope of the bell, which had turned in descending, he could not make their want of air known above, and both were found dead when the bell was drawn up soon

after, although the water had not touched them. Of a hundred and forty-six Englishmen who in the year 1750 were made prisoners at Calcutta, and were thrown into the close dungeon, since called the *black-hole*, only twenty-three survived the few hours of their confinement, and one of the most appalling recitals of human suffering existing on record, is what these persons had afterwards to make.

We know generally of the life-supporting action of air, that it consists in some change operated by the air on the blood; and we know that the function of respiration has merely to bring air and blood together in the cavity of the chest, that this change may take place. The blood while in the chest is moving along a part of its circle, in vessels of extreme minuteness and thinness, and the air at each inspiration rushes in among these, so that every globule of blood passes within its influence. And the blood, which, after having served the purposes of the body, arrives at this part of its course black and impure, immediately after its exposure to the air, enters the left chamber of the heart, of a beautiful scarlet colour, and thence departs to carry new life to the general system.

The minute vessels through which the circulating blood is strained in the chest do not hang loose in the cavity, but are supported by running through spongy masses, called the lungs, which consist chiefly of these vessels and of thin membrane formed into cells. The cells at every inspiration receive fresh air through the cartilaginous windpipe which branches into them, and at every expiration they

return the changed air by the same channels to the atmosphere. The lungs of a child, before birth, are perfectly collapsed, or without the least air in their structure, and hence are dense enough to sink in water ; but after breathing, they retain a portion of air, and will float. This fact has been accounted a test of whether a child had been born dead or alive ; but because putrefaction, &c. will cause air to be in lungs which have never breathed, the criterion may be fallacious.

The chest is a large cavity, of form approaching to that of a common bee-hive, bounded laterally by the encircling ribs, behind by the spine, and before by the sternum, and divided below, from the abdomen or belly, by a strong membranous and muscular expansion, called the diaphragm. The ribs, in the natural state, hang obliquely downwards from their posterior attachments, and on being raised in front, they widen or increase the size of the cavity, as already explained at page 228. The cavity is farther enlarged by the descent of the diaphragm, which may be regarded as both the floor of the chest and the roof of the abdomen, and which being convex upwards like a dome, by contracting itself to a more flat condition, sinks out of, and enlarges the chest, while it descends into and diminishes the abdomen, or at least causes protrusion of its sides.

Now on the chest being enlarged by the rising of the ribs and descent of the diaphragm, or by either singly, the air rushes into it through the mouth and windpipe, exactly as air rushes into a common bellows through its pipe, when the valve

is shut and the two boards are drawn apart ; and air is again expelled from the lungs by the contraction of the chest, as from the bellows by the approximation of the boards. Into both cavities air enters, because with the enlarging dimensions, the air which was within dilates, and becomes less powerfully tense or resisting against the external pressure of the atmosphere, and so allows more air to rush in to restore the equilibrium. The air is expelled again by the contraction of the cavities, because, by being compressed, its elastic force or tension becomes greater than that of the external air, which it therefore easily repels, and so in part escapes.—By immersing in water an India-rubber bottle, and then opening and shutting it, the entrance and exit of fluid in this manner may be rendered very apparent.

That the air admitted to the chest should have the fullest action on the blood passing there, it was necessary that the spongy mass of lungs in which the blood-vessels ramify, should occupy the whole of the cavity, and be equally distributed. Now while the equable distribution is effected by the uniform elasticity or resilience which belongs to the structure of lung, the complete filling of the cavity is obtained, not by general attachments between the lungs and the ribs or sides of the chest, as might be expected, but by the following means, equally simple, and still more perfect. The spongy mass of the lungs is completely covered by a strong adherent membrane, called the pleura, through which air cannot pass ; between this membrane and a similar lining of the chest



there is no air or empty space, and therefore, in the rising and falling of the ribs during respiration, this membrane remains always in contact with the lining of the ribs, just as a bladder put into a bellows as a lining, with its mouth secured around the nozzle, is filled and emptied, and remains in contact with the interior of the bellows, in all the states of dilatation, as if there were attachments in a thousand places. This construction allows the lungs to have a singular freedom of play during all the motions of the body; a freedom farther provided for by their being divided into five portions or lobes, which slide upon one-another: of these, three occupy the right side of the chest, and two with the heart occupy the left. The right and left sides of the chest are rendered cavities quite distinct from each other by the *mediastinum*, a strong membranous partition. The mechanical disposition of the contents of the chest, as now described, is productive of certain consequences which it is important to understand;—for instance,

If a wound be made in one side of the chest so as to admit air, the lungs of that side collapse in obedience to their weight and elasticity; and as the chest afterwards enlarges and diminishes in respiration, air more easily enters and leaves the space around the collapsed lung, through the wound, than it can enter or leave the lung itself through the windpipe; because in the first case it has no force to overcome, and in the second the elasticity, weight, and inertia of the lung oppose. Thus the lungs of the wounded side become collapsed and useless. If such a wound, therefore,

were made into both sides of the chest at once, even without hurting any part within, the person, unless assisted, would die of suffocation. The kind of assistance required in such a case, is first to press the ribs down so as to empty the chest of air as much as possible, and then to keep the wounds close or covered while the ribs rise again; the air, of course, will then enter by the natural road, the only one left, to fill the chest, and will distend the lung, and reach the blood in the pulmonary vessels as usual. Then by straining with the muscles of the chest, as in the action of blowing, and at the same time preventing the breath from escaping by the mouth or nose, all the air which had entered by any wound in the chest may be expelled. In Benjamin Bell's system of surgery, which was long the manual of practitioners, counsel on this head was given the very contrary of that required, and, of course, any patient treated according to it, must have been lost.

In cases of dangerous hemorrhage from a lung, caused by a wound in the side, the proper practice is to allow the lung to collapse, as now explained, that the hemorrhage may be checked; and when the danger is past, the treatment above described is to be adopted to restore the natural play of the lung. Life may be supported for a long time by the lung in one side of the chest.

In cases of hemoptysis, or spontaneous bleeding from the lungs, a disease so often fatal, life might sometimes be saved or prolonged by making an opening between two of the ribs, and allowing the lung to collapse. The affected lung is often

clearly pointed out by the circumstances ; and the opening, when properly made, would be no more dangerous, than in the case where, by a similar opening, water or pus is discharged from the chest.

The same operation has been tried as a forlorn hope in pulmonary consumption. This disease is often limited to the lung of one side, and as the alternate stretching and collapse of the diseased lung during respiration, together with the contact of the air, powerfully prevent an ulcer there from healing, or inflammation from subsiding, a new chance of recovery is given by allowing the diseased lung to collapse and remain at rest.—Some cases are recorded where cure is said to have followed this operation, and certainly, where the circumstances are favourable for it, and where death must ensue unless it can save, it is worth trying.

When ribs are fractured, it is the practice to put a bandage round the chest, so as for the time to prevent almost entirely the respiratory motion of the ribs, and the breathing is then performed chiefly by the rising and falling of the diaphragm or floor of the chest, as above described. Although a person with broken ribs is wisely for a time subjected to this unnatural restraint, it is surely the height of folly to inflict the same on healthy beings, as is yet, however, so commonly done among young women, and often to the destruction of their health, by the fashion of bracing the body in tight stays.

The force of a healthy chest's action in blowing is equal, as stated in last section, to about *one pound* on the inch of its surface ; that is to say, the

chest can condense its contained air with that force, and can therefore blow through a tube the mouth of which is two feet under the surface of water. In the opposite action of sucking or drawing in air, the power is nearly the same.—In both actions it is possible to use the cavity of the mouth separately from that of the chest ; and the mouth being smaller, with stronger muscles about it in proportion to its size, it can act more strongly. Some men can suck with the mouth so as to make nearly a perfect vacuum, or to lift water nearly thirty feet. An expert operator with the blow-pipe can keep up an uninterrupted blast by shutting the mouth behind, while he inhales, and replenishing it as is required in the intervals.

In *coughing*, the *glottis* or top of the wind-pipe, by a curious sympathy of parts, is first closed for an instant, during which the chest is compressing and condensing its contained air, and on the glottis being then opened, a slight explosion, as it were, of the compressed air takes place, and blows out any irritating matter that may be in the air-passages ; just, only with inferior force, as the burst from the chamber of an air-gun discharges its bullet.—This shutting of the glottis to allow the compression of the air, and the subsequent opening to allow the discharge, may recur at very minute intervals, and many times for one fill of the chest, as is instanced in hooping-cough.—The action of coughing is often produced by irritation from a cause which cannot be removed by coughing, as inflammation of the chest, or tubercles ; or even by irritation in a distant part, as when chil-



dren are teething, or when the stomach is overloaded.

*Sneezing* is a phenomenon resembling cough, only the chest empties itself at one throe, and chiefly through the nose, instead of through the mouth, as in coughing. The irritation that produces sneezing is generally in the nose; but, as in the case of cough, sneezing may occur from distant sympathies; witness that from worms in the bowels.

*Laughing* consists of quickly repeated expulsions of air from the chest, the glottis being at the time in the condition to produce voice; but there is not between the gusts, as in coughing, complete closure of the glottis.

*Crying* differs from laughing almost solely in the circumstance of the intervals between the gusts of air being longer. Children laugh and cry in the same breath, and it is often difficult to mark the moment of change.

*Hiccup* is the sudden stopping, by a closure of the glottis, of a strong inspiration at its commencement. If the inspiratory effort be afterwards continued, it may cause air from the atmosphere, or half-digested food from the stomach, to enter the œsophagus.

In *straining* to lift weights, or to make any powerful effort, the air is shut up in the lungs, that there may be steadiness and firmness of the person. At such a time, by the compression and condensation of air around the heart and large blood-vessels, the blood is determined violently outwards from the chest, and often rises to the

head, with force that produces giddiness, or even apoplexy,—and the eye will sometimes become suddenly blood-shot, from a small vessel giving way; and leech-bites will break out afresh.—The force of this pressure outwards is measured, as already stated, by a column of about two feet of blood; and this is therefore the measure of the additional arterial and venous tension in the body generally.

*Suffocation* is the name given to what happens when the supply of air to the lungs is in any way prevented. The blood, not then refreshed by the approach of the air, rises to the brain unfit for its purpose, and confusion of thought is immediately produced, soon followed by convulsion and death.

When this happens from mechanical obstruction at the narrow entrance of the windpipe, as in croup, by the tenacious films thrown off from the inflamed lining of the air-passages, life may be saved by making a new entrance for air through the windpipe, lower down in the neck, and keeping it free by a little tube inserted, until the obstruction above be removed. Where children die with croup, it is frequently not from the violence of the constitutional disease, but from detached films thus accidentally sticking in the narrow entrance of the air-passage.

In the cases of strangling and hanging, the tight binding of the rope or ligature crushes inwards the cartilaginous rings of the windpipe, and shuts the air-passage. It may also cause apoplexy, by arresting the passage of blood to and from the head;

and there may be dislocation of the cervical vertebræ of the spine.

In *drowning*, communication with the atmosphere is cut off altogether by the supernatant water. If during submersion the chest expands, it can receive water only instead of air. The nerves and muscles, however, at the entrance of the wind-pipe, are so irritable, as to be immediately excited by the contact of any unusual matter, and for a considerable time they keep the passage shut against the liquid seeking entrance. It is partly on this account that the body of a person, after submersion in water and apparent death, may often, if recovered within a moderate time, be restored to life.

The apparatus of the Humane Society for the recovery of persons apparently drowned, includes a bellows for producing artificial respiration. This bellows resembles a common bellows, except that its flap or valve, instead of being internal, is external like a large flute-key, and has a spring to close it, obedient to the finger of the operator. The bellows receives its charge of fresh air on being expanded, while the valve is open ; it sends the charge into the lungs on being compressed while the valve is shut ; it withdraws the charge again on being expanded with the valve shut ; and the impure air is thrown out to the atmosphere on its being compressed with the valve open. These changes repeated and continued, produce the artificial respiration required. It is most important to remark here, that if air be injected into the lungs, either in too large quantity or very sud-

denly, instead of recalling or sustaining life, it is as certain a means of killing as a dagger driven through the heart. This truth has been but lately known, and ignorance of it has probably decided the fate of many persons, treated with a view to recovery after submersion. The operator should reflect that he is dilating the delicate air-cells of the lungs with the force of an hydraulic press; and that if he do so very suddenly, although to a small extent, he still may rupture many small blood-vessels, before they can empty themselves so as to yield. In a bellows for the purpose of artificial respiration, there should be the means of checking its opening to suit the capacity of the patient's chest, and there should be a cock in the pipe or nozzle, to regulate the speed of the passing air.

In addition to the artificial breathing for the recovery of suspended animation, it is often necessary, to restore natural warmth to the body, to rub the limbs in aid of the circulation, to administer stimulants by the mouth, to excite by galvanism, &c.

It seems to be an error, and probably often a fatal error, in the present mode of treating persons apparently drowned, to use cold instead of warm air for the artificial respiration. Thus while the important object of restoring the temperature of life is sought by all external means, the great inconsistency is committed of blowing cold air upon an internal surface of the body more extensive than the external; and until that reciprocal action of the air and blood begins, which con-



stitutes the slow combustion of natural respiration, every bellows-full of cold air admitted, brings back with it a portion of the remaining central warmth, and may thus chill so as to make the recovery impossible :—as a fire which has fallen very low may be immediately extinguished by the same action of a bellows, which a little before would have made it blaze. Air might easily be heated for the purpose of respiration by pouring boiling water into a vessel containing it, and then connecting the bellows with that vessel by a fit pipe, or by making the bellows draw through a pipe partially immersed in hot water :—a quart of boiling water, has heat enough in it to warm many gallons of air to blood-heat. This plan would not only avoid the mischiefs arising from the cold air, but by affording the means of applying warmth even higher than that of life, it might probably furnish the most useful of all stimulants to the parts about the heart. A healthy man can breathe with impunity, air that is much hotter than boiling water.

Late physiological investigations have shewn that the breathing, or mechanical action of the chest in respiration, is so dependent upon the influence of the brain, as to be disturbed and even stopped when the brain is embarrassed : they have shewn further that the action of the heart is dependent on the breathing, but not on the brain, except as the cause of the breathing—for that respiration kept up artificially, will preserve the circulation and the life for a considerable time after the brain has altogether ceased to act, or even has been removed from the body. Now, some inte-

resting experiments of Mr. Brodie, have proved that certain poisons are fatal, merely because they suspend for a time the action of the brain—through which suspension the actions, first of the chest, and then of the heart, cease, and death ensues: but that in such cases, if the action of the chest be maintained artificially, the circulation and life of the body will be for a time continued, and the brain may gradually recover from the effect of the poison, so as to resume its office. Thus certain cases of poisoning, which formerly would have been fatal, may now end in recovery.

An important application of this discovery is to the treatment of cases of convulsion, particularly those occurring from teething or other irritations in infancy. The respiration ceases in these cases often only because the action of the brain is suspended; and if the respiration be continued artificially, the circulation and life will also continue for a time, during which the brain may recover itself, either spontaneously, or in consequence of remedies employed, and life may be saved.—The chest of an infant is comparatively so small, that it may be filled from the mouth and windpipe of a grown person, with air which has not descended to that person's lungs, and therefore has not been rendered unfit for respiration; and on the little chest being afterwards compressed by the hand, the air will return. The air may be blown directly into the child's mouth through a thin handkerchief laid over the mouth, or it may pass through a tube inserted into the nostril or trachea:—to prevent it from passing into the stomach, the larynx

must be pressed against the œsophagus during its entrance. Let all who try this remedy, keep present to their minds the danger of inflating too much.

Any medicated air is generally inhaled by a patient from an oiled-silk, or other air-tight bag, or from a light gasometer (see page 444). When the compound nature of our atmosphere was first discovered, great advantages were anticipated to medicine from the use of pneumatic or aerial mixtures. These expectations have not been realized, but the subject still remains highly deserving of research.

#### THE VOICE AND SPEECH.

The chest and air-passages, with certain additional parts, constitute the organs of voice and speech.

An inquirer into the constitution of the universe around him, meets with few things calculated more to surprise him, than that faculty in the human mind by which it can associate the ideas of objects with any arbitrary signs, so closely that the ideas are afterwards excited by the signs almost as vividly as by the objects themselves. The inhabitants of China, for instance, having contrived many thousand grotesque characters, and determined what object each shall recall, when a Chinese by study becomes familiar with these, he may have his bodily eye poring over pages of crooked and unseemly scratches, while his mental eye through them sees only a pleasing succession of the most beautiful imagery of nature: and the characters may be rendered intelligible to the

deaf and dumb man as well as to him who speaks ; and they serve as media of thought and communication through many provinces and countries of which the spoken languages have no common resemblance.

But if the ready remembrance of *visible* signs be wonderful, which have a permanent existence, and which often may have some resemblance in form to the things signified, how much more wonderful is it that an *audible* sign, that is, a passing sound or fugitive breath, called by man a word, should serve as well ; and that by a succession of mere sounds, having so little natural connexion with the things signified, that they are totally different in different countries, and are changing with fashion from age to age, any train of thought may be made to pass through the minds of an audience, so as to excite and to leave impressions almost as vivid as from realities ! Such, however, is the fact, and it is greatly owing to this and to a correspondent faculty of producing at will a sufficient number of distinguishable sounds, that man owes his elevation above the brutes of the field. His godlike powers of intellect would have remained dormant and unknown, had he wanted the faculty of comparing his invisible thoughts with those of his fellow men, and of arranging and recording them by means of signs.—Written language is a double remove from the objects themselves, being *visible signs* not of things, but of the *audible signs*.

The admirable apparatus by which man is enabled to produce a sufficient variety of sounds to answer his purposes, passes generally under the



denomination of *the organs of speech* ; because the act of using sounds which have meanings assigned to them is called speech. It consists of the chest for containing air ; of the larynx or cartilaginous box, with its narrow aperture called the glottis, at the top of the windpipe, for producing the voice, and varying its pitch ; and of the short tube of the mouth, with the tongue and lips, for farther modifying the voice.

In the chapter on acoustics, we explained that sound is the name given to the effect produced upon the ear by certain tremblings conveyed to it generally through the medium of the air ; and we explained how air, forced from the human lungs through the opening at the top of the windpipe, causes the elastic lips of that opening to vibrate, and to excite the tremblings. We have now to show that this sound, in passing forward from the top of the windpipe, may be modified at the will of the individual, in a great variety of ways—a variety, however, which is still very simple.

The modifications of voice easily made, and easily distinguishable by the ear, and therefore fit elements of language, are about fifty in number ; but no single language contains more than about half of them. They are divisible into two very distinct and nearly equal classes, called, for reasons now to be explained, *vowels* and *consonants*.

Those of the first class are the simple voice issuing through the open mouth, and influenced only by the degrees in which the mouth is opened and elongated. They may be continued as long as there is breath to issue from the chest, and it is

for this reason that they are named *vowels* or *calling sounds*. The roman letters, A, E, I, O, U, as generally pronounced on the continent of Europe, and of which the sounds correspond nearly to those of *aw*, *a*, *e*, *o*, and *oo*, of English writing, indicate the most easily distinguishable vowels. Sound passing through the mouth in its most natural state of relaxation, is heard as the modification expressed by the Italian E (or the *a* of the English word *care*): if the mouth be then widened, the sound becomes the A (as in the English word *bar*); if the mouth be narrowed, we hear the I (or the *e* of the English *tedious*); if the mouth be elongated and at the same time widened, we hear the O (as in the English word *bore*); and if more elongated but narrowed, we hear the U (as in the English *rude*). The possible number of vowels, however, is as great as the possible degrees in which the dimensions of the mouth may be altered. About twenty of them are sufficiently distinguishable, but few languages comprehend more than twelve. Modern art can produce the vowel sounds mechanically by means of tubes of certain dimensions.

The alphabets of Europe are very faulty in not all using the same characters for the same sounds, and in not having, according to the true intent of an alphabet, a character for each distinct sound. In English one letter is used for several sounds, as A in *water*, *far*, *fat*, *fate*, where it indicates four sounds perfectly distinct. In repeating the English alphabet, the A is pronounced as the broad E of the Italians and of continental Europe, and the

E as the I; and the I (in *tide*, for instance), as the diphthong AI of more correct alphabets; and the U (in *muse*), as the diphthong IU. In consequence of the changes which the English have made in the meaning of the roman letters, they now experience increased difficulty in learning modern continental languages; and their own pronunciation of the ancient languages, to all but themselves, is ridiculous, and almost unintelligible. The same cause renders the pronunciation of English difficult to foreigners, and thus restricts much, in other countries, the cultivation of English literature.

To explain the second class of the modifications of sound, called *consonants*, we may remark, that while any continued or vowel sound is passing through the mouth, if it be interrupted, whether by a complete closure of the mouth, or only by an approximation of parts, the effect on the ear of a listener is very remarkable, and is so exceedingly different, according to the *situation* in the mouth where the interruption occurs, and to the *manner* in which it occurs, that many most distinct modifications thence arise. Thus any continued sound as A, if arrested by a closure of the mouth at the external confine or lips, is heard to terminate with the modification which we choose to express by the letter P, that is, the syllable AP has been pronounced; but if under similar circumstances, the closure be made towards the back of the mouth by the tongue rising against the palate, we hear the modification expressed by the letter K, and the syllable AK has been pronounced; and if the

closure be made in the middle of the mouth by the tip of the tongue rising against the roof, the sound expressed by T is produced, and the syllable AT is heard,—and so of others. It is to be remarked, also, that the ear is equally sensible of the peculiarities whether the closure precedes the continued sound or follows it : that is to say, whether the syllables pronounced are as above, AP, AT, AK, or on the contrary, PA, TA, KA.—The modifications of which we are now speaking, appear then not so much to be sounds, as distinguishable manners of beginning and ending sounds ; and it is because they are thus only perceivable in connexion with vocal sounds that they are called *consonants*.

Now in the mouth, considered as a vocal tube, there are three situations, in which interruption of voice or breath may most conveniently be made, and there are six modes of making it at each ; so that eighteen distinct interruptive modifications or consonants hence arise. These we shall now describe.

The three great *oral positions*, as they may be called, are,

1st. At the external confine of the mouth, or lips, giving the *labial* articulations, of which P is an example.

2d. In the middle of the mouth, where the tip of the tongue approaches the palate behind the teeth, producing the *palatal* articulations, of which T is an example.

3d. Near the back of the mouth, where the



body of the tongue approaches the palate, giving the *guttural* articulations, of which K is an example.

And the *six modes* in which the voice or breath may be affected in passing through each of the three positions of the mouth, are,

1st. A sudden and complete stoppage, producing what may be called a *mute* articulation: *viz.* P, in the labial position; T, in the palatal; and K, in the guttural. (See here the general table of articulations three pages farther on, which table may be considered as representing the tube of the mouth, with the letters so placed as to shew in what situations in the mouth the sounds represented by them are severally produced.) A mute may also be made by stopping the breath exactly at the teeth, *viz.* a *dental mute*; but it is hardly distinguishable from the *palatal mute*, produced just behind it, and being less perfect, is not used.—Some awkward speakers substituting it for the proper mute, are said to *speak thick*.

2d. A sudden shutting, as in the last case, but the voice being allowed to continue until the part of the mouth behind the closure be distended with air.—This produces the *semi-mutes*, B, D, and G (as heard in the syllables AB, AD, AG), for the three positions. There might be a dental *half-mute*, but it is no more used than the *dental-mute*, and for the same reasons. If the sides of the tongue be depressed after it has taken the position required for T or D, the sound L is produced; and the letter is, in the table, placed below D,

although the sound from being continuable, is not in any sense a *mute*.

3d. The positions closed as for the mutes, while sound is allowed to pass by the nose.—Thus arise the *semi-vowels* or *nasals*, M, N, NG, for the three positions.—NG (as in *king*) is a simple sound, although our imperfect alphabet has no single letter for it. The nasal sound of the French language, which gives it so great a peculiarity, approximates to the English NG, but differs from it in the sound being allowed to pass by the mouth, as well as by the nose. It is pointed at by the small *n* in the table, and like the other sounds which do not occur in the English language, is here printed in the *Italic* character.

4th. Breath only (or whisper) allowed to pass at the three oral positions nearly closed.—Hence come the sounds which we call *aspirates*, viz. F, for the labial position, TH and S, for the palatal, and CH (heard in the Scottish word *loch*), for the guttural; the TH and CH are simple sounds, although each expressed in Britain by two letters. The TH is heard in the word *bath*, and is the sound expressed by the single letter  $\theta$  of the Greeks. The CH is heard in the German, *ich*, and is the  $\chi$  of the Greeks. The *soft aspirate* TH, is more easily made by pressing the tongue gently against the teeth, and allowing the breath to pass all around, than by the true palatal approximation of parts, and the *soft dental aspirate*, therefore, is used in preference to the *palatal*. The letter S is the *hard palatal aspirate*, and differs from the *soft palatal aspirate* TH, in the breath being made to

issue with greater force, and only by a narrow space over the centre of a rigid tongue, instead of on all sides of a soft tongue, as for TH. French people, on first attempting to pronounce TH, substitute for it the D, or the S, or the Z (which is nearly related to S, as explained below). The author has found it easy to enable them to pronounce the TH at once, and perfectly, by explaining its nature as above. If we depress the sides of the tongue while pronouncing S, we produce the simple sound expressed by the English double letter SH ; just as by depressing the sides of the tongue while making D we produce L.

5th. Using *voice* in the same manner as *breath* or *whisper* is used for the aspirates.—This produces the sounds called *vocal aspirates*, viz. V, TH, Z, J, and GH. TH *vocal aspirate*, is heard in *bathe*, as contrasted with the *simple aspirate* in *bath* ; Z comes from the S position, only with *sound* instead of *breath* ; SH pronounced with *voice*, becomes the J of the French in the word *je*, or the sound heard in the middle of the English word *vision*. GH is a simple sound used in German, but not in English.

6th. Shaking the approaching parts in the three positions.—We thus make *vibratory sounds*, of which the middle position gives the common R, the only one of them used in England. Some bad speakers of English, however, make the *labial vibratory* by shaking the P in such words as *property* ; and many use the *guttural*, which is the *burr* of Northumberland, and the common affectation in Parisian speech, termed *parler gras*, or *grasseyer*.

Table of Articulations.

Mute.	Semimute.	Semivowel or nasal.	Aspirate.	Vocal Aspirate.	Vibratory.	
P	B	M	F	V	<i>pr</i>	LABIAL.
.	.	.	th	th	.	Dental.
T	D	N	S	Z	R	PALATAL.
.	L	.	sh	J	.	{ with the edges of the tongue depressed.
K	G	ng n	ch H	gh	ghr	GUTTURAL.

## Additional Remarks.

The sound of H is an *aspirate* produced even behind the situation of the *guttural aspirate ch* : it is, indeed, merely a forcible passing of the breath through the very back part of the mouth or throat.

CH, in such words as *chain*, means T before *sh*.

J, as heard in the English name *John*, is a compound sound, *viz.* D before the simple J of the table, which is the S of *vision*.

LL. The liquid or double LL of the French, as heard in the word *paille*, is merely L with the letter Y begun to be pronounced after it. It is heard in the English words *billiard* and *halyard*, and would be their terminating liquid were the



syllable *ard* not pronounced. The double LL of the Welch, as in the name *Lloyd*, has the first L pronounced as an *aspirate*, that is, as a whisper, and the second in the ordinary way.

GN. The soft GN of the Italians and French, is the English N with Y begun to be pronounced after it. It is heard in our word *tanyard*; and in the Italian words *pegnio bagnio*; and in the French word *craignent*.

C, in English, stands always either for S or K, as in the words *certain* and *car*, and has no sound proper to itself.

Q in English expresses the sound of the letter K, with U following it; and yet, uselessly, U is always written after Q.

X in English means either KS, as in the word *axe*, or GZ, as in the word *example*.

The consonants are best heard by sounding them with voice before them: that is to say, by making them rather terminate a syllable than begin it; pronouncing B, D, G, thus *eb*, *ed*, *eg*, rather than their common alphabetical names *be*, *de*, *ge*.

The labial sounds may be made either by the two lips, or by one lip and the opposite teeth. F may be pronounced, for instance, by the lips only, or by the lips and teeth; and some persons awkwardly make it by the under teeth and upper lip.

The letters Y and I, in most modern languages, stand for nearly the same sound. In English, for instance, *bullion* and *minion*, might be written, *bullyon* and *minyion*, without suggesting a change of pronunciation. In the words *yard*, *you*, *yes*, &c.

the Y is a short I, very closely joined to the following sound.—W is also thus a short U, as perceived in the words *war*, *we*, &c.

The author believes the analysis of articulations to be the best basis for a system of short-hand written characters. He has tried such a system, and has found it exceedingly convenient.

*Lisping* is chiefly the habitual substitution of the aspirate TH for the S and SH.

*Whispering* is articulation without voice ; that is to say, articulation while breath only is passing.

*Stuttering*, *stammering*, or *hesitation of speech*, are terms implying an interrupted articulation, accompanied generally with more or less of straining and distortion of feature. It is remarkable with respect to this defect, that when the present work was first published, scientific or regular medicine had taught as yet no certain cure for it, although the frequent success of non-professional, and often ignorant individuals, by a mode of treatment which they solemnly bound their patients not to divulge, proved the cure, in certain cases, to be both possible and not difficult.—The author's attention had been drawn to the subject some years before, by an interesting case submitted to him, of stuttering connected with other disease ; and it was in analyzing the subject with a view to the treatment of that case, that he framed the analysis of articulation contained in the preceding pages, and drew up a part of the additional observations which are now to follow. A cure was obtained ; but as the case possessed a favourable peculiarity in the powerful mind of the individual, to which the author attri-

buted great importance, and as he had little leisure from his ordinary professional duties, to pursue the subject, or to ascertain in what respects his plan might differ from that employed by the most successful of the practitioners who concealed their proceedings, he gave his remarks in former editions of this work, merely as continued elucidation of the subject of speech. He is now, however, enabled to state, that his analysis has completely detected the nature of the morbid affection, and that it directs simple and effectual means of relief. He declined meddling with many cases offered to him after the original publication of his work, from the impression that the cure in the instance mentioned above, was owing at least as much to the ingenuity and perseverance of the patient, as to his suggestions, and therefore, that his professional superintendence of the discipline required for ordinary cases would demand care and attention which he could not spare ; but subsequent experience has proved to him that the business is altogether very simple and easy, and as regards children, may be managed by any intelligent instructor of youth who chooses to devote attention to it, while grown individuals will often be able to relieve themselves by the study of the present section ; and he hopes that in very few cases will the counsel of a person familiar with the anatomy and actions of the organs be found to fail.

Command over the organs of speech is acquired in the same way, as over all the other muscular organs of the body ; those, for instance, used in walking, skaiting, fencing, performing on musical

instruments, &c. : that is to say, at first, a distinct act of volition is required for every individual movement ; but the law of association or habit rendering the actions easier with each successive repetition, they are at last formed into connected tribes or trains, which appear as obedient to a single wish as the separate elements originally were. A child at first exerts as distinct and powerful a volition to pronounce the syllable *pa*, as after some practice to double the syllable and make *papa* ; or after still more practice, to pronounce the longest and hardest word of the language :—nay, at last, where there is strong and healthy power of association, complete sentences, and even rounded periods of eloquence, are poured out like single words, the mind of the speaker seeming at liberty, after each sentence or period is begun, to meditate and prepare that which is next to follow. As the faculties of locomotion and of speech are acquired in infancy and early childhood, persons no more recollect how they gradually acquired them, than how their limbs grew ; but the progress described above may be watched by any individual of mature years in his own person, while he is learning such an art as that of playing on a musical instrument. He will find, that at first, every finger which is moved to produce a note, obeys a distinct thought and volition ; that soon short trains of connected notes become obedient to the will almost like a single note ; that then by degrees, longer and longer trains or passages become familiar, until at last the instrument is as obedient to the practised player, as voice is to the singer, or speech to the orator.



There is great original diversity among individuals as to their powers of muscular association, and therefore, also, as to their aptitude for acquiring the various faculties of which we have been speaking. Thus some children walk well before a year, others require a much longer time, and some never succeed perfectly until they have had lessons from the dancing-master or drill sergeant.—So, again, many people, by ear and imitation alone, learn easily to play on musical instruments; but others must begin by studying the written notes, and the precise *fingering* by which each note is produced on the instrument; and many, unless the notes be constantly before them, cannot play at all.—So again, all persons may be said to learn to speak at first by ear and imitation; but many grow up to a certain age with defects, which judicious lessons from parents or other tutors are required to remove; and there are some, as stutterers, who, owing to a naturally weak or irregular association, or to some accident in early life, which has strongly affected their nervous system, retain defects which no ordinary teaching can correct. It appears, then, that an analysis and scale of articulate sounds, with minute description of the organic actions required to produce them, like the scale which we possess for music, in the *gamut* and rules for *fingering*, should give nearly the same assistance to the speaker, which the *gamut* gives to the player. The table and analysis contained in the preceding pages is intended to supply this information. It is constructed from minute consideration of the organs

of speech while in action. It agrees in many respects with the common grammatical divisions of elementary sounds, but in others it pursues the analysis in a different way, and considerably farther. A person who understands it well, will have, while he speaks, an intelligent perception of what he is doing, in addition to the parrot-like faculty of habit, or of repeating by rote, and will thus command any desired sound by two powers instead of one. And, as a musician, when his musical memory fails him, finds help by thinking of his written notes and their relation to his instrument, so may a stutterer, when hesitating at any sound, receive benefit by thinking of the letter which represents it, and of the position of the organs required for that letter. Then by frequent practice in making the particular combinations of sound which are difficult to him, he may strengthen the useful habit, and ultimately overcome his defect.

The most common case of stuttering, however, is not, as has been almost universally believed, where the individual has a difficulty in respect to some particular letter or articulation, by the disobedience of the parts of the mouth which should form it to the will or power of association, but where the spasmodic interruption occurs altogether behind or beyond the mouth, *viz.* in the glottis, so as to affect all the articulations equally. To a person ignorant of anatomy, and therefore knowing not what or where the glottis is, it may be sufficient explanation to say, that it is the slit or narrow opening at the top of the windpipe, by

which the air passes to and from the lungs, being situated just behind the root of the tongue. It is that which is felt to close suddenly in hiccup, arresting the ingress of air, and that which closes, to prevent the egress of air from the chest of a person lifting a heavy weight or making any straining exertion; it is that also, by the repeated shutting of which a person divides the sound in pronouncing several times, in distinct and rapid succession, any vowel, as o, o, o, o. Now the glottis during common speech needs never be closed, and an ordinary stutterer is instantly cured, if by having his attention properly directed to it, he can keep it open. Had the edges or thin lips of the glottis been visible, like the external lips of the mouth, the nature of stuttering would not so long have remained a mystery, and the effort necessary to the cure would have been suggested to the most careless observer: but because they were hidden, and professional men had not detected in how far they were concerned, and the patient himself had only a vague feeling of some difficulty, which, after straining, grimace, gesticulation, and sometimes almost general convulsion of the body, gave way, the uncertainty with respect to the subject has remained. Even many persons who by attention and much labour had overcome the defect in themselves, as Demosthenes did, have not been able to describe to others the nature of their efforts, so as to ensure imitation: and evidently the quacks who have succeeded in relieving many cases, but in many also have failed, or have given only temporary relief, have not really understood

what precise end in the action of the organs their imperfect directions were accomplishing.

Now a stutterer, understanding of anatomy only what is stated above, will comprehend what he is to aim at, by being farther told, that when any continued sound is issuing from his mouth, as when he is humming a single note or a tune, the glottis is necessarily open, and therefore, that when he chooses to begin pronouncing or droning what we have already described to be the simplest of vocal sounds, namely, the vowel *e*, and in its less distinct modification, as heard in the English word *certain*, or in the French word *que* (to do which at once no stutterer has difficulty), he thereby opens the glottis, and renders the pronunciation of any other sound easy:—or if, when speaking or reading, he joins his words together, nearly as a person joins them in singing (and this may be done without its being at all noted as a peculiarity of speech, for many persons do it in their ordinary conversation), the voice never stops, the glottis never closes, and there is of course no stutter. The author has given merely this explanation or lesson, with examples, to persons who before would have required half an hour to read a page, but who immediately afterwards read it quite smoothly; and who then, on transferring the lesson to the speech, by continued practice and attention, obtained the same facility with respect to it. There are many persons not accounted peculiar in their speech, who in seeking words to express themselves, or while coming to a decision, often rest between their words on the simple sound



of *e* mentioned above, saying, for instance, hesitatingly, “e..... I e..... think e..... I shall,”—the sound never ceasing until the end of the sentence, however long it may be delayed. Now a stutterer, who, to open his glottis at the beginning of a phrase, or in the middle after any interruption, uses such a sound, would not even at first be more remarkable than a drawling speaker, and he would only require to drawl for a little while, until practice facilitated his command of the other sounds. Although producing the simple sound mentioned is a means of opening the glottis, which by stutterers is found very generally to answer, there are cases in which other such means may be more suitable, as the intelligent preceptor will soon discover.—Were it possible to divide the nerves of the muscles which close the glottis, without at the same time destroying the faculty of producing voice, such an operation would be an immediate and certain cure of stuttering.

While the spasmodic closure of the glottis, as above described, is the common cause of stuttering, there are also cases in which the cause is a spasmodic prolongation of some of the aspirates or semivowel sounds, as of *s*, *m*, *l*, &c. Fortunately, however, the substitution of the simple sound is equally the cure for all.

While the cure of many stutterers has been accomplished by their own efforts, after the study of what is written in this section, for others, and particularly for young people, the following have been found to be farther useful rules or forms of direction; and a commentary upon them making

them perfectly intelligible, would seem to comprehend all that can be communicated upon the subject.—1. Familiarise yourself with the idea of a *continued sound*, as of the roar of the sea or waterfall, or the note of an organ-pipe, and feel that your speech is to be as uninterrupted.—2. Then never stutter more, but substitute always the simple continued sound for any threatened defect, and rest upon it until power be felt to overcome the difficulty.—3. Never repeat words or syllables.—4. The simple sound must become the first syllable (*closely* joined) of every difficult word, until the morbid habit be weakened. The object of all these directions is to enable the patient, first, to substitute universally the *drawl* for the *stutter*, and then, as soon as possible, to discard the *drawl* too.

The view given above of the nature of stuttering and its cure, explains the following facts, which to many persons have hitherto appeared extraordinary.—Stutterers often can sing well, and without the least interruption; for the tune being continued, the glottis does not close.—Many stutterers also can read poetry well, or any declamatory composition, in which the uninterrupted tone is almost as remarkable as in singing.—A person who draws in a deep breath before beginning to speak, as he cannot long retain the air, and the glottis must be open to let it escape, is to a degree secured against the occurrence of stuttering. The secret remedy of an American quack, who years ago got much money from Englishmen, was the direction thus to fill the chest before beginning

to speak. A Dr. McCormac, also, who published a work on this subject, founded on the erroneous idea that stuttering was an effort to speak while *inhaling* air, instead of while *exhaling*, gave the same direction.—The cause of stuttering being a weak and easily disturbed association of certain muscular actions, we have the reason why any degree of anxiety or dread as to speaking well, exceedingly increases the defect; and why many stutterers, who cannot make themselves intelligible in society, still, when alone, can speak and read as perfectly as any other person. This explains also why many stutterers, who have gone to live for a time at the houses of pretended curers of their defect, have felt themselves singularly relieved from the moment of entering the house; because, knowing that they were expected to speak ill, they had no fear of disagreeably attracting attention, and therefore had their powers much more at command. These persons, on returning to the world, have generally stuttered as badly as ever, but many of the asserted cures of stuttering, with certificates obtained from the parties at the time, have been of the nature now described.—The cause of stuttering being so simple as above described, one rule given and explained may, in certain cases, instantly cure the defect however aggravated, as has been observed in not a few instances; and this explains also why an ignorant pretender may occasionally succeed in curing, by giving a rule of which he knows not the reason, and which he cannot modify to the peculiarities of other cases.—The same view of the subject explains why the

speech of a stutterer has been correctly compared to the escape of liquid from a bottle with a long narrow neck, coming—"either by hurried gushes or not at all:" for when the glottis is once opened, and the stutterer feels that he has the power of utterance, he is glad to hurry out as many words as he can, before the interruption recurs.

The study of the table of articulations leads to the immediate correction of many minor defects in utterance, and is calculated to facilitate the acquirement of foreign languages. A lisping person, for instance, is cured at once, by being told that the tongue must not touch the teeth in pronouncing the letter S; and a Frenchman who deems it impossible for him to pronounce the English sound of TH, discovers that he cannot avoid doing so if he rests his tongue softly against his teeth, opened a little, and then forces breath or sound to pass between the tongue and teeth.

Several of the modern languages of Europe consist of nearly the same elementary or radical words, and differ among themselves chiefly by the prevalence in each of certain terminations, and of one or other of the related and convertible sounds classified in the analysis given above. A student, therefore, who, by analytical investigation, or considerable practice, has become impressed with the peculiar genius of a language, may invent, or determine by analogy, even before minute study, the majority of those words belonging to each which have sprung from a common origin. This remark is so true with respect to the languages of Italy,



Spain, Portugal, and even France, that to persons familiar with them, they are at last listened to rather as the same language spoken by different individuals, than as languages in themselves different.

*Ventriloquism* is the name commonly given to the art by which an individual can assume characters of voice and speech which are not natural to him, and thus, although alone, can imitate closely a conversation held between two or more persons.

The most remarkable diversity is obtained by speaking during inspiration instead of, as usual, during expiration. The voice so produced is more feeble than the ordinary voice, and when accompanied by other circumstances favouring the illusion, it may suggest very completely the idea of a boy calling from the bottom of a pit, or from the interior of a chimney, &c. An unsuspecting peasant may be tricked into unloading his hay-waggon by an expert ventriloquist, who makes him believe that there is a poor child packed under the heap and ready to be smothered there.

A person, by a little practice, may acquire the power of producing, without the slightest apparent motion of the lips or countenance, all the articulations except the labial, and of them the F, V, and M, may be tolerably imitated by parts behind; hence by avoiding words in which P and B occur, such person may speak without visible movement of the organs, and if he assume the attitude of a listener, he may make the deception of ventriloquism complete. The idea which some authors have had (*see Good's Study of Medicine, &c.*) that the articulations of the ventriloquist are

not produced by the tongue and mouth, as in common speech, is altogether an error. The art, carried to a certain degree, is not very difficult, as any person may ascertain who tries it after considering minutely the nature of common speech.

There are also striking varieties of voice producible by speaking with a more acute or grave pitch than usual, and with different degrees of contraction of the mouth ; but these may be more properly called *imitations* than *ventriloquism*.

The variety of effect in sound which the human organs are capable of producing is truly surprising. There are adepts in the art of imitations, who not only mimic the speech of all ages and conditions of the human race, but the songs of birds, the cries of animals, and even not a few of the sounds produced among inanimate things. Many of these performances become in the highest degree ludicrous, and furnish favourite amusements in our theatres. A Mr. Henderson, of London, about the end of the eighteenth century, used to *kill his calf*, as he called it, to crowded houses every night. After dropping a screen between him and the audience, he caused to issue from behind it all the sounds, even to the minutest particular, which may be heard while a calf is falling a victim in the slaughter-house ;—the conversation of the butchers, the struggling and bellowing and quick breathing of the frightened animal, the whetting of the knife, the plunge, the gush, the agony ;—and, revolting as the occasion is in itself, the imitation was so true to nature, that thousands eagerly went to witness the art of the mimic.

The following cases of inanimate sound may be closely imitated by the mouth : The working of a grindstone, including the noise of the water into which it dips, the rough attrition of the steel upon it, and the various changes occurring with change of the pressure ;—the working of a saw cutting wood ;—the uncorking of a bottle, and the gurgling noise of decanting its contents ;—the sound of air rushing into a room in a winter night by a crevice or key-hole—and many others.

It has already been explained, that voice depends on the vibration of the two edges or lips of the slit-like opening of the glottis, by which the air passes to and from the chest. The number of vibrations in a given time, or the pitch of voice, depends, of course, on the length and tension of these edges. The length is varied by the positions of the arytenoid cartilages, and the tension by the action of small muscles which act on these ; and the cavity of the mouth is enlarged or lessened to accord with the number of vibrations, by the rising or falling of the tongue and larynx which form its bottom. The peculiarities of individual voices must depend chiefly on the size and firmness of the cartilaginous box of the larynx, the strength of the muscles of the chest which force the air through the glottis, and the pliancy of the moving parts.

The glottis is smaller in women than in men, and hence their pitch of voice is higher :—with reference to music, the difference is generally of an octave, or eight notes.

The voice of a boy, in regard to pitch, is gene-

rally the same as that of a woman ; but at the age of puberty, the sounding organs in the male enlarge suddenly, and render the voice stronger than before, and by nearly an octave graver. The voice of an eunuch is the voice of the boy continued, because the change called puberty does not take place in him.

Complete loss of voice, for longer or shorter periods, is often experienced by persons while in feeble states of health. The vibrating, and therefore sounding edges of the glottis, which are usually kept tense by the operation of certain muscles, on these ceasing to act, owing to the state of their nerves, will not vibrate as required, and the voice is lost. Slight colds suffice in many people to produce this effect : in others of morbidly sensitive or delicate nervous temperament, it follows fatigue, or any other cause of debility. Articulation is not destroyed by loss of voice ; and whispering answers passably the end of vocal speech.

No intelligent mind can meditate on human speech and its influence in the world, without being roused to vivid admiration. But for speech, the most gifted individuals who have lived, had they existed at all, could have been little superior in their worldly state to the leading oxen of our herds, or to leading monkies in the woods. As regarded the rest of mankind, Homer and Newton would have lived in vain. At the present day, among the natives of Australasia, where language may be said scarcely yet to exist, human nature is seen thus brutishly debased ; while, on the other



hand, in the history of the world, we may trace, as a consequence of more perfect speech, all the progress which has been made in arts and civilization. By language, fathers have communicated their gathered experience and reflections to their children, who in their turn become fathers, have transmitted them to succeeding children, with new accumulation; and when in the course of ages the precious store had increased, until mere memory could retain no more, the art of writing arose, making language visible and permanent, and enlarging without limit the receptacles of knowledge; and then the art of printing came, which now rolls the still swelling flood into every hamlet and every hut. Language thus, at the present moment of the world's existence, may be said to bind the whole human race of uncounted millions into one gigantic rational being, whose memory reaches to the beginnings of written record, and retains imperishably the important events that have occurred; whose judgment analyzing the treasures of memory, has already discovered many of the sublime and unchanging laws of nature, and has built on them the arts of life, and through them, piercing far into futurity, sees distinctly many events that are to come; and whose eyes, and ears, and observant mind are, at this moment, in every corner of the earth, watching and recording new phenomena, for the purpose of still better comprehending the magnificence, and simplicity, and beauty of creation.

## THE DIGESTION.

The doctrines of fluidity, illustrating and illustrated by certain phenomena of digestion.

The animal body may be seen at first, in the maternal ovary, as a single speck of mucus ; but from possessing life—wonderful life—the little nucleus, placed in new circumstances, begins to gather to itself substance from around, and it increases in bulk. For a certain time it remains attached to the body of its parent, and draws the material of its increase from its parent's blood ; but after that time it is alone and entirely dependent on its own resources. Then we see brought into play that extraordinary apparatus now to be described under the name of the *digestive* or *assimilating organs* ; which, under the direction of a nervous energy, can, out of almost any kinds of dead animal or vegetable matter, build up the beautiful living body to perfect maturity of size, and form, and faculty. And it is not only while their bodies are growing that animals require to take in and assimilate new matter, but also after maturity, in order to repair the waste of constant action. Supply of fuel and water to the steam-engine is not more necessary than of aliment to the living body.

Some of the less perfect animals take in sustenance almost like vegetables, by absorbent tubes that open on their surface ; but by far the greater part receive it first into an interior cavity, where it undergoes certain preparation, and is then offered to internal absorbents, which drink up what is

required, and carry it into the circulating blood. This internal cavity is called *a stomach*. Its form and appendages differ exceedingly in different animals, according to the nature of the substances which serve for their sustenance, and to various other circumstances.

In man, the process of digestion has the following steps. The food is first received by the *mouth*. It is there broken or torn into small portions by the cutting and grinding wedges, called *teeth*, with which the *jaws* are armed ; at the same time a fluid called *saliva* is mixed with it, poured out from glands around, so as to reduce it into a pulpy mass : this mass is then pushed backwards by the *tongue* to enter the long tube called the *gullet* or *œsophagus*, which, by successive contraction of circular fibres, propels it down to the pouch of the *stomach*, placed under the edge of the left ribs. From the internal surface of the stomach a liquor oozes, called the *gastric juice*, the most general solvent in nature, and which, attacking the received food, soon reduces it, of whatever kind, to the state of a pultaceous mass, named *chyme* ; in this state it enters the narrow *intestinal* canal which is continued from the stomach, where it almost immediately receives a mixture of bile and pancreatic juice poured out from the liver and pancreas. After this mixture, as it gradually passes on, a chemical decomposition and separation of parts takes place, and the pure nutriment of the body assumes the state of a milky fluid floating among refuse. This milky fluid, called *chyle*, is taken up all along the canal by the num-

berless absorbent mouths of the vessels called *lacteals*, and is then carried to the *thoracic duct*, and by it into the blood to supply the waste. The intestinal canal is about six times as long as the body, affording therefore a very extensive surface from which absorption may take place. That remnant of the chyme which the absorbents refuse, mixed with various depositions or secretions, continues its journey onwards, and is periodically discharged.

Much of the process which we have now described is *mechanical*, as will appear immediately ; other parts of it are *chemical*, such as the solution of the food by the gastric juice, the separation of the milky chyle, &c. : and parts are *vital*, such as the afflux, just when wanted, of saliva, gastric juice, bile, &c., and the muscular and absorbent actions. He who neglects the study of any one of these three classes of particulars, must have a very incomplete acquaintance with the function.—We proceed now to explain the mechanical or physical circumstances connected with digestion.

The abdomen may be considered as a vessel full of liquid, in which therefore there is pressure in all directions, increasing with the depth (see hydrostatics), and increased also by the action of the surrounding muscles which form the sides of the cavity.

The justness of this view of the abdomen becomes evident, when we consider that only moistened or semifluid food descends into the stomach, that drink follows, and that gastric and other juices



are poured out to mix with the food as it passes on to occupy the long intestinal canal; and then that the intestines externally are perfectly smooth, and are moistened by the constant secretion of a lubricating serum, so that they slide among each other, without sensible impediment from friction. The abdomen, therefore, is in fact a roundish smooth vessel filled with a thick fluid, which is farther contained in a perfectly pliant and smooth-coated tube.

Thus any part of the contents of the stomach and bowels, in a living man, is supported like water in surrounding water, and therefore, if the whole contents be of equal specific gravity, no part can descend or advance by its weight. Neither can any general pressure, or contraction of the surrounding parietes, hasten, except at the moment of expulsion, the motion of any contained matter—as has, however, often been supposed; nor can it help to empty one part into another—the stomach, for instance, or the gall bladder, into the small intestine.

For the same reason, however, the very slightest contractile action of any containing part is sufficient to dislodge its contents—gravity as a resistance being neutralized by the surrounding fluid. And when the gall-bladder, or stomach, or any part of the intestinal tube, becomes so full, as to put the elasticity of the coats ever so little upon the stretch, that circumstance alone, unless some muscular action oppose, will cause a discharge of the contents.—The natural action of the intestinal canal is a successive contraction of its circular

fibres from above downwards, propelling the contents, just as if a small ring or tube were put round the canal and pushed forwards.

These considerations make evident the common error of supposing that vomiting can, by the sudden compression of the abdominal viscera, *mechanically* emulge or clear the obstructed biliary ducts. If general pressure of the abdomen could produce this and similar effects, a descent in the diving-bell should be a powerful remedy in human maladies; for nearly fifteen pounds on the inch is added to the ordinary abdominal pressure, at a depth of thirty feet in water.

We hence see also the kind of error into which our predecessors fell so generally, when they attributed much of the digestive power of the stomach to its simple pressure upon the food. The idea probably arose from the contemplation of the stomach or gizzard of a fowl, which is a powerful gristly substance, answering the purpose almost of a mouth and teeth, as well as of a stomach.

It is an error also to suppose that quicksilver, which is sometimes swallowed to remove obstruction, runs through the bowels simply by its weight. On first entering the loose small intestine, it must drag the part containing it to the bottom of the abdomen, and in that situation the whole intestine must pass round it, nearly as a rope passes through a ring fixed to the floor. When the mercury arrives at the part of the intestine called the *cæcum*, where the farther course lies upward along the fixed arch of the colon, it probably can be dislodged only by the patient's lying down. Any

useful operation of quicksilver, in such cases, may be in its stimulating the bowels, by dragging or displacing them, in the manner above described.

When the abdominal muscles, which are the containing sides of the cavity, become tense, whether from unusual fulness of the cavity, or from their own action in any of the straining exertions, a variety of important mechanical effects ensue. Thus,

*A full stomach* produces—tension and projection of the belly—projection of the diaphragm into the chest, causing hurried breathing, and impeding speech and singing—expulsion of blood from the abdominal vessels, and, therefore, congestions elsewhere, as in the arteries of the head, sometimes producing apoplexy.

*Abdominal fulness*, as in *dropsy*, *tympanitis*, *corpulency*, *pregnancy*, &c., produces most of the effects now mentioned in an aggravated degree. If dropsy be allowed to proceed too far without tapping, the patient will die of suffocation from the rise of the diaphragm.—The external veins of the legs and abdomen of a dropsical person are generally turgid, because the blood is pressed into them out of the abdominal cavity, and because the passage of blood through the abdomen is impeded. In tympanitis, or windy dropsy, as it has been called, the viscera hang down in the abdominal cavity, while the air occupies the upper part. In common dropsy, the viscera float about and are supported.

*Straining* or strong action of the abdominal

muscles, and therefore also pressure on the abdominal contents, occur with almost every considerable bodily exertion ; for the abdominal muscles are the antagonists of the great muscles on the back and about the spine, and must always come into play with them, to give firmness and rigidity to the trunk of the body. This may be seen remarkably in the actions of lifting, running, wrestling, &c. As the abdominal muscles cannot act in a continued way and strongly, unless the ribs, from which they arise, become nearly fixed, the ribs are supported during exertion by the intercostal muscles, and by the air in the chest, then confined by the closure of the air-passages : hence there is generally compression in the chest also when the abdomen is compressed, and the blood is squeezed towards the extremities from both cavities at once. It is important to remark also, that in what are called the strong actions of the chest, as *coughing*, *sneezing*, *blowing*, &c., the abdominal muscles are at least as active as the pectoral : by pulling down the ribs to which they are attached, they narrow the chest, and by compressing the abdominal contents, and thus raising up the diaphragm, they shorten the chest.

The following cases exemplify the effects of straining.—The lifting of a great weight, or making any great exertion, drives the blood up to the head ; as is marked by the sudden redness of the face.—Coughing or vomiting will cause closed leech-bites to bleed afresh, and sometimes will overcome the action of the sphincter of the bladder or rectum : coughing will also produce



vomiting.—Straining to empty the bladder, rectum, or womb, or the effort of vomiting, will cause the rupture of a blood-vessel in the white of the eye, with consequent effusion of blood there.—Apoplexy often happens under the same circumstances, from the breaking of a vessel in the brain.—The rupture of a varicose vein, or of aneurism, generally happens during exertion.—And during exertion, the protrusion is likely to occur at any weak part of the abdominal cavity, of some portion of its contents, producing what is called *hernia* or *rupture*.

*Vomiting* is produced, not by the forcible contraction of the stomach, as was long supposed, but chiefly by the action of the parietes of the abdomen.—This is proved by the fact that the stomach has been removed from a living animal, and a sheep's bladder containing liquid has been substituted for it, in connection with the gullet above and the intestine below; and on then injecting an emetic drug into the veins of the animal, vomiting has taken place, as if the stomach had been there and unhurt. From this we see why, to prevent regurgitation of the food, during exertion, the upper orifice of the stomach requires to be almost as strongly closed, as the sphincters below.

A small pump—in this application called the *stomach-pump*—has lately been used in medical practice, for removing poisons from the stomach in cases where the action of vomiting could not be excited. It has already saved many lives. It resembles the common small syringe, except that there are two apertures near the end, instead of

one, which, owing to valves in them, opening different ways, become what are called a *sucking* and a *forcing* passage. When the object is to extract from the stomach, the pump is worked while its sucking orifice is in connexion with an elastic tube passed into the stomach, and the discharged matter passes by the *forcing* orifice. When it is desired, on the contrary, to throw cleansing water or other liquid into the stomach, the connection of the apertures and the tubes is reversed.

As a pump may not be always procurable when the occasion for it arises, the profession should be aware, that in many cases a simple tube will answer the purpose as well, if not better. Such a tube being introduced, and the body of the patient being so placed that the tube forms a downward channel from the stomach, all fluid matter will escape from the stomach by the tube, as water escapes from a funnel by its pipe; and if the outer end of the tube be kept immersed in liquid, there will be during the discharge a syphon-action of considerable force. On then changing the posture of the body, water may be poured in through the tube to wash the stomach, and may by the same channel be again discharged. Such a tube, made long enough, might, if desired, be rendered a complete bent syphon, the necessary preliminary suction being produced by a syringe, or by an assistant, who acts through an interposed vessel.

But there is a still easier mode than either of these now described, of dislodging poison from a torpid stomach, *viz.* merely to place the patient so that the mouth shall be considerably lower than the

stomach,—as when the body lies across a chair or on a sofa, with the face near the floor,—and then if necessary, to press on the stomach with the hand. The cardiac orifice opens readily in such a case, and the stomach is emptied like any other inverted vessel.

Useful as the pump may prove, upon occasions, in evacuating the stomach, its more ancient office of injecting the enema is still the more important—and recent experience seems to shew that such injection may become a remedy of more extensive utility than had yet been suspected. From an erroneous opinion, that what had been called the *valve of the cæcum* acts as a perfect valve, allowing passage downwards only, few practitioners have ventured to order much liquid to be injected, for fear of overstretching the lower part of the intestine; and the possibility of thus, by injection, relieving disease situated above the supposed valve, has scarcely been contemplated. It is now ascertained, however, that fluid may be safely thrown in even until it reach the stomach.—Perhaps few, if any cases of obstruction of bowels, could resist the gentle force of penetrating water, so that a mechanical remedy of certain effect may, in many cases, be substituted for the drastic purgatives and pernicious bleedings now used, and often used in vain.—From what has been said above of the abdomen and the intestinal canal, it appears that an injection tends to spread itself with singular uniformity over the whole. This tendency may be rendered obvious to sight, by throwing a sheep's intestine, recently extracted, into a bucket

of water, and then pumping water in at one end : —a stream will issue strongly at the other end, although several feet distant, almost immediately, and without any intermediate part having become very sensibly tense.—Of course, in the living body, in cases of spasm or obstruction, the liquid must be thrown in against resistance very gradually.

That case is called *introsusception* of the bowel, in which an upper portion falls, or is received into a portion below (as one part of the finger of a glove may be received into another part), and the receiving portion of the bowel, mistaking the received for descending food, holds it fast. This occurrence forms a complete obstruction, and generally proves fatal. Many infants, with irritable bowels, die of it.—Now a copious enema, such as we have described above, is almost a certain cure. The liquid advances until it reaches the part where the portion of gut has been swallowed by gut below ; and as it cannot pass without pushing the introsuscepted portion back to liberty, it effects the cure.

The *perpetual syringe*, or *little valved pump*, of which we have been speaking as lately used in applications to the animal body, can inject or withdraw any quantity, and is therefore very superior, for almost every purpose, to the old large syringes which had no valves, and which, without being removed, could inject only once their fill. With well-adapted additional apparatus, the same instrument will answer for many purposes, as for throwing up the enema, clearing the stomach,



transfusing blood, exhausting cupping-glasses, relieving the over-distended breasts; for the lotio vesicæ, vaginæ, vel urethræ, &c. No surgical apparatus is now complete without one. The annexed outline represents such a syringe. The aperture *c* is rendered a *sucking orifice*, by a valve at it, opening inwards; and *a* is the forcing orifice, in consequence of having its valve opening outwards: *b* is the piston, with its handle. The valves may be variously made, or a single *double-way cock* may be used instead of both. Convenient dimensions for the syringe, are from four to six inches for the length, and from three-quarters of an inch to an inch and a quarter for the diameter.



For a case of diseased rectum, where it was necessary to use an enema daily, or oftener, the *enema funnel*, represented here (from the funnel-shaped mouth *a* downwards, and exclusive of the part above *a*), was contrived, and was found more manageable by the patient than any other instru-



ment. If the tube *a b* be about two feet long (it may be of metal, oiled silk, caoutchouc cloth, &c.), the liquid column contained in it suffices to overcome the ordinary abdominal resistance; but if a very short tube be used, the open funnel *a* must be converted into a close vessel, as represented here by the dotted line above the funnel, having a bladder, or other air-

tight bag, *d*, connected with it, and a bottle-neck and cork, or a cock, at *c*, for admitting the enema. On pouring in the liquid at *c*, the air in the vessel *c a* is forced into the bag, and on then closing the opening at *c*, and compressing the bag, it is evident, that any desired degree of injecting pressure may be exerted on the enema. This apparatus is both cheaper and more simple than any syringe, and is equally effectual; and the bag never being wetted, lasts long: *b* is a cock kept shut until the moment of injection.—The principle of substituting, in an injecting apparatus, the pressure of a liquid column for that of a piston, was first suggested in this work; and yet, since the publication of the work, more than one patent has been taken for it, for parties seeking to convert it to their profit.

By viewing the abdomen in the true light of a vessel or bag filled with liquid which is seeking to escape in all directions, we have the explanation of several circumstances connected with *hernia* or *rupture*; in which accident the containing sides of the abdomen in some part have given way, allowing a portion of the viscera to escape, so as to form a tumour under the skin.

Hernia may be produced by all causes which strain or weaken the muscles: as by leaping, lifting great weights, coughing and sneezing, lying with the belly across a bench or yard, as sailors do on ship-board, over-distension of the belly by eating and drinking, corpulency, dropsy, pregnancy; debility of muscle from dissipation, &c.

The reason that a rupture increases so rapidly after it has once begun is, that the protruding part

is truly a fluid wedge, of which, therefore, the opening force increases with the diameter. (See Hydrostatics.) This shews the singular importance of arresting the accident at its very commencement. The trusses used to repress rupture were described at page 249.

In attempting to return any part of the abdominal contents which may have escaped as a rupture, we should recollect, that a soft uniform compression or squeezing exerted upon the tumour by the hands of the operator, if greater than the internal pressure of the abdomen, is slowly pushing back again any fluid matter that can ooze inward from the tumour; and by thus gradually lessening the size of the tumour, may effect the desired object, without the adoption of the last resource, of cutting parts to widen the inlet. When, in such a case, the operator sees clearly with the mind's eye what is passing under his fingers, his efforts may often be successful, where a less intelligent individual would fail. No man practises medicine long, whatever his nominal department, without having opportunities of saving life, or of preventing a serious operation, by judicious management of recent hernia. The barbarous old fashion of lifting the patient by the heels and shaking him, that the weight of the bowels might drag back again the part which had escaped, was founded on ignorance of the fact, that the weight of the bowels in all positions of the body, is supported almost entirely, not by their attachments, but by the surrounding parts.

The function of digestion or assimilation sketched in the preceding paragraphs, by which the animal body assumes foreign matters from around, and

converts them into its own substance, is a subject of study little inviting in some of its details, but taken altogether is one of the most wonderful which can engage the human attention. It points directly to the curious and yet unanswered question—what is LIFE? The student of nature may analyze with all his art those minute portions of matter called *seeds* and *ova*, which he knows to be the rudiments of future creatures, and the links by which endless generations of living creatures hang to existence: but he cannot disentangle and display apart their mysterious LIFE! that something under the influence of which each little germ, when placed in due circumstances, swells out, to fill an invisible mould of maturity which determines its forms and proportions. One such substance thus expands into a beauteous rose-bush; another into a noble oak; a third into an eagle; a fourth into an elephant—yea, in the same way, out of the rude materials of broken seeds and roots, and leaves of plants, and bits of animal flesh, is built up the human frame itself, whether of the active man, combining gracefulness with strength, or of the gentler woman, with beauty around her as light. How passing strange, that such should be the origin of the bright eye, whose glance pierces as if the invisible soul were shot with it—of the lips which pour forth sweetest eloquence—of the larynx, whose vibrating fills the surrounding air with music; and, more wonderful than all, of that mass shut up within the bony fortress of the skull, whose delicate and curious texture is the abode of the soul, with its reason which contemplates, and its sensibility which delights in these and endless other miracles of creation.



## PELVIC APPARATUS.

*The Secretion of the Kidneys, &c.*

OF the large quantity of fluid daily taken into the human body, much escapes with the breath, as is proved by the visible condensation of it in frosty air, or on any cold polished surface held near the mouth ; part escapes by the skin in perspiration ; but the greatest part, after having answered the purposes of the constitution, is separated from the blood by the two secreting organs, called the kidneys, and from them by fit channels, is carried off, holding in solution various other matters, which the system does not require. The kidneys are situated in the loins, one on each side of the spine ; and the constant drain of liquid from them passes down by two membranous canals called *ureters* into the bladder, from which the liquid is again expelled through the urethra, at considerable intervals, according to the rapidity of accumulation.

The bladder is a curious membranous and muscular reservoir, of which the fibres can contract so as to expel the last drop, and yet can yield so as to admit a quart or more.

The passage of fluid downwards through the ureters from the kidneys to the bladder resembles in some respects the passage of blood in the veins. Authors have erroneously supposed that the weight of the fluid sufficed to cause its descent : but the bladder and ureters are enclosed in a common cavity with the intestinal canal ; and while this is full of a semi-fluid mass of greater specific gravity

than the urine, the latter is not only supported by the surrounding pressure, as water would be supported by water, but is forced upwards or resisted, as water would be in honey or treacle : in descending, therefore, it obeys some other force than gravity, namely, that of the secreting vessels and heart.

The *ureters*, *bladder*, and *urethra* are the seats of some of the most distressing diseases to which the human frame is liable. Two classes of these being relievable chiefly by mechanical means, require to be shortly considered here. They are, *obstructions in the urethra*; and *concretions*, or *stones*, as they are called, *in the bladder*.

*Obstructions* or strictures in the urethra are generally consequences of an inflammation, which has destroyed the dilatibility of a part of the canal. They appear as if a thread or a bit of tape were tied round the canal, so as to narrow its calibre. Constant irritation, which destroys the general health, fits of fever, broken rest, and even death from total suppression of urine, have been common consequences of stricture.

Until within a recent period, the treatment of such obstructions was pursued very generally according to a blind routine. The attempt was made either to bore them open by wedges, called bougies, often of doubtful and tedious operation, or to destroy them by caustic passed down to them in the end of a bougie, which caustic often hurt the part of the canal anterior to them, or eat out false passages about the stricture, or opened blood-vessels so as to cause dangerous hemorrhage.

Struck by the defective state of this branch of the healing art, the author of the present work, while abroad, and situated where he had interesting opportunities of observation, had bestowed considerable attention upon it, and he then contrived and tried several new means of relief. These were afterwards brought more extensively into use and improved, and others were added, by his brother Dr. James Arnott, superintendent surgeon in the service of the Hon. East-India Company, who gave a minute account of them in a treatise on urethral diseases, and a supplement, published in the years 1818 and 1820. They have become perhaps still better known in France than in England, through the work of Dr. Ducamp, which described them, and which, having been submitted to the French Institute, and most favourably reported upon by the appointed authorities, soon became a standard treatise in the country :—in France also, the philosophy of mechanics had been studied by surgeons more generally than in England. It is painful to be obliged to add, that Dr. Ducamp, as regarded these instruments and the views of disease and treatment which had suggested them, concealed the fact of his being only a translator. The imposition was not discovered at the time of his death, which happened two years afterwards, hastened apparently by the fatigues of the extensive practice which the report of the Academy brought upon him. The author has had so much pleasing intercourse with enlightened and honourable Frenchmen, that it pains him to have this fact to relate.

The objects aimed at by the *new means* were,—to ascertain the exact condition of the diseased canal—to facilitate the passing of instruments in cases of difficulty—and to effect a permanent cure. The following *seven* of these means may here be particularized.

1st. *An examining sound*: being a bougie with the point formed of a softer tenacious material, in which fibres of cotton or silk are mixed to prevent any portion from being broken off or detached during use. This sound pressed against the obstruction, takes a correct impression of its anterior face, and shews the magnitude and exact position of the still remaining opening.

2d. *An expanding or dilator sound*, which is a small tube with a dilatable button at its extremity. The button consists of a little bag, which is passed through the stricture empty, and is filled with fluid after it has passed. It readily discovers any other strictures beyond the first, and to a certain degree the state of each.

3d. *A conducting canula* or tube, open at both ends. It is passed down to the stricture, for the purpose of supporting and directing small bougies seeking entrance through very narrow strictures, or of guarding the caustic bougie in its approach to the place of its action.

4th. In cases where the attempt to open the passage has failed by all common means, a conducting tube is first introduced, and through it six or more small bougies are passed side by side, so as to probe the whole face of the stricture at the same time. It is thus



scarcely possible that the opening should not be found.

5th. Were even this means to fail, the conducting tube may be filled with water, under any degree of pressure, which water will either open the passage for the small bougies, or will itself act as the sharpest and most insinuating of all instruments. The stricture, by whichever means opened, will then allow the urine to escape. As patients might fear that water forced towards a bladder already too full would only increase the evil, J. Arnott waited for more numerous proofs of the utility and safety of the practice, before strongly recommending it: Dr. Amussat of Paris has since published a statement of numerous cases of retention thus relieved.

6th. A *dilator* for widening the stricture, after a small instrument can be passed through it. It is intended as a substitute for the *bougies* and *sounds* of former times. The chief objections to these last are, the painful friction, the danger of making false passages, the tediousness and imperfection of the cure, and that they cannot dilate any part of the canal beyond the size of its orifice, through which they have to pass, and which during health is the narrowest part of the canal.

The dilator consists of a tube of thin membrane introduced while empty into the stricture, on a ball-pointed wire, and then filled with fluid by a syringe, so as to dilate the stricture, with any degree of force, from the mere filling of the part to the strain of the hydrostatic press, sufficient to tear the strongest texture that disease can form.

The dilating tube is about two inches long, and its end next to the operator is fixed to the point of a small catheter, through which the distending fluid is injected. The tube is formed of thin silk riband of various sizes, with the edges joined. It is lined with prepared gut of the cat or dog, which is almost as thin as gold-beater's skin, although very strong and water-tight; and it is covered with the same to give the smoothest and softest possible external surface. When complete and enclosing its blunt wire, it is still much less bulky than the bougie which would be required for the same case. Thus, it passes easily; it cannot tear the canal or make false passages, it can enter through a small orifice, and then dilate to any desired extent; and its greatest advantage is, that by swelling so as to follow the yielding of the stricture, it can effect at one application, what only a succession of hard bougies, during long treatment, could accomplish. In one day it has often removed disease, which had resisted other means for months or even years.

Some practitioners and critics, not understanding the law of fluid pressure (explained at p. 255), objected at first to the dilator, that a little water or air pressed into it by a syringe, would be unable to overcome much resistance. Had they seen the instrument lifting so readily as it does, a heavy weight laid upon it, or snapping a strong ligature tied round it, they would not have had this prejudice. It was objected, also, that the instrument would do mischief by dilating the urethra before and behind the stricture more than the stricture

itself; now its dimensions being determined and fixed by those of its silken tunic, it never can *distend* beyond the diameter chosen, and therefore, if of the proper size, it can only *press* on the stricture itself. It was also said, that this instrument requires, in the operator, greater manual dexterity and acquaintance with mechanical philosophy than many surgeons possess; but this is merely saying that the arts are progressive, and that the accomplished surgeon of the present day is more dexterous and intelligent than his predecessors of the last century. It is not accounted a reason why the delicate apparatus of the oculist should fall into disuse, that all surgeons are not able to apply it.

Some attempts had been made before, to construct a *dilator of fluid pressure*, but they produced nothing of value. For urethral purposes, a simple gut or intestine is worse than useless, for, being yielding in its texture, the surgeon can never know truly the size of his instrument, and therefore may do much mischief by it. Dr. Ducamp, in speaking of the dilator, allows that he did not first invent it, but then, from ignorance of what constitutes its true value, he takes praise to himself for simplifying and improving it, by throwing away the silk, and using the gut only.—A variety of metallic dilators have been contrived and used by English surgeons since the publication of *Arnott's Treatise on Strictures*, but although manageable with less trouble than the fluid dilator, they want its chief merits.

The *dilator* is applicable to many other purposes

in surgery besides that now mentioned,—as for removing stricture of the gullet, and of the rectum, for checking hemorrhage in deep wounds, for dilating wounds as a tent, &c. And the operation of lithotomy was saved to a gentleman, whom Sir Astley Cooper and the author of this work were attending together, by the dilator opening a *fistula in perineo*, so that a large stone was extracted without cutting. The dilator has also served in removing stones from the female bladder.

7th. Another improved means for the treatment of stricture, described in the *treatise*, is a mode of applying caustic for its entire destruction, but so as not to touch any other part of the canal. Formerly the caustic was applied *to the face* or anterior part of the stricture, and therefore had almost always to destroy a portion of the healthy canal before it could reach the narrowest fibres:—the extent of such portion depending on the distance from these fibres of the part where the lining of the canal began to be drawn inwards by them. This explains why not unfrequently a hundred applications of caustic were made in a single case, and why during such treatment false passages were often bored, and other mischiefs produced. Now by applying the caustic *within* the stricture at once, a single application generally suffices. To accomplish this, a ring of caustic is placed (as described in the *Treatise*, and in the *Cases*) on a bougie of peculiar construction, about an inch from its extremity; and the bougie being then passed down to the stricture through a tube or conductor, and the point being passed beyond



the stricture, the caustic is guided to the very spot where it is desired to act.\*

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\* Du Ducamp incurred a singular risk in giving himself out as the first proposer of the instruments and practice described above ; for he was already known as a translator of English medical books, and the *Treatise on Strictures* of J. Arnott had been held up to public attention two years before by the various medical reviews, in terms such as the following : “ We have carefully perused this little volume, and are of opinion that it is by far the best systematic work on the subject in the English language.”—“ It is a judicious compilation, interwoven with much original and acute observation ; and it gives publicity to instruments which promise to be of essential benefit to operative surgery.”—*Medico-Chirurgical Review*, January 1819.

Perhaps Dr. Ducamp imagined that the slight alterations proposed by him in the construction of three of the new instruments, might be a shield to him when detected : but as a chief merit was in the analysis of the subject which suggested such instruments, and not in the mere mechanical fulfilment of intentions, even a considerable improvement in the instruments would not have been a sufficient excuse. His changes, however, were either trifling or retrograde. His metallic *dilating sound* is less perfect than metallic sounds contrived by J. A., but not described, because the fluid dilating sound was found to be preferable. His *porte-caustique* is defective in not distending the stricture at the moment of applying the caustic ; and his mode of making a *dilator* without the silken tunic, renders it not only an useless, but a dangerous instrument :—indeed, such as obliged him to use the caustic in almost every case. His silence with respect to the *liquid probe*, favours the conclusion that he did not understand it, although Dr. Amussat of Paris has since used it with much success :—and the same remark applies to the *double catheter* (see Arnott's cases), or *sonde à double courant*, as it has been called by those who have since used it in Paris.

The following are extracts from the report made by the commissioners of the French Institute, Doctors Deschamps and Percy, in May 1822, on the subject of Ducamp's work, entitled *Traité des retentions d'urine*.

(1.)

2 x

*Stone in the bladder*, is another disease reliev-able chiefly by mechanical means.

The urine, as secreted in the kidneys, contains dissolved in it, a variety of substances, which

“ This treatise concerning a most important malady, because one of the most common and painful which affects humanity, has appeared to us to merit more than ordinary attention.

“ When, some years ago, your same commissioners had to express their opinion of another work on this subject, they commended the zeal and industry of its estimable author (Dr. Petit); but they could not conceal that there were still imperfections in his modes of treatment; and also that they were almost entirely either borrowed or imitated from the English.

“ The work of Dr. Ducamp now leaves us, however, nothing more to desire, and we have no longer reason, as regards this subject, to envy our neighbours. Although a volume of moderate size, it is incomparably more complete and full of matter than the bulky treatises lately published in other countries.

\* \* Ducamp leaves all these authors far behind him, whether as to the soundness of his doctrines, the superiority of his trials, or the invention of instruments.

“ He takes a print or model of the stricture by an instrument of his invention, called *Sonde Exploratrice*. (Arnott's examining sound, page 674.)

“ For introducing bougies in difficult cases, he uses an elastic gum tube, which he calls *conducteur*. (Described above, page 674.)

“ Mr. D. has invented, for measuring the length of strictures, &c., an instrument, which when introduced, enlarges beyond the stricture. (*The dilating sound*, page 675.)

“ The nitrate of silver, or common caustic, is what he uses for destroying strictures, but he employs it in a new manner, which appears to us to give it new powers, and to deprive it of all its former dangers. \* \* He carries the caustic into the stricture by means of his *porte caustique*. (See above, page 678, No. 7, of Mr. Arnott.)

“ .....To enlarge the canal at the morbid part to its true calibre, he uses an instrument which he names a *dilatateur*.

under certain circumstances, separate and assume the solid form,—as sugar separates in small crystals from cooling syrup, or salt from cooling brine :—and it is thus that those minute grains are produced, which we call *urinary gravel*. A single particle of gravel remaining by any accident in the bladder, soon attracts to itself more matter of the same kind, and becomes the nucleus or centre of an increasing mass, which is what we call the *stone in the bladder*.

In a second Tract by the author's brother, published in 1820,\* the following paragraph appears :

“ From the severe suffering of the patient labouring under stone in the bladder, and the remedy being an operation so painful and dangerous, that many wear out their lives in certain misery, rather than submit to it; it has arisen that no part of surgery has excited more attention, either in the medical profession or out of it.† No very im-

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(*Dilator*, page 661.) He does not conceal that this instrument had been imagined before him, but he has the merit of perfecting it, and of reducing to practice what before had only existed as a project.

“ .....In rendering justice to the able men who have preceded Ducamp, we must still say, that no one has displayed so much industry, dexterity, and talent, and we think that he has high claims to the confidence of patients and the gratitude of the profession, and that his work merits the eulogium of the Academy.

(Signed) “ DESCHAMPS,—PERCY, Reporters.

“ CUVIER, ..... Secretary.”

\* Cases illustrative of the Treatment of Urethral Obstructions and of Stone. By James Arnott.—Longman and Co., 1820.

† The Catalogue of authors who have written upon stone, occupies in Plocquet's *Literatura Medica*, no less than twenty-nine very closely printed quarto pages.

portant change in the treatment of this disease has now been made for upwards of a century ; and, indeed, it has appeared to be the opinion of modern surgeons, that the manner of operating practised by Cheselden, about a century ago, and which has been called the ‘glory of English surgery,’ was so nearly perfect, as to leave little room for improvement. The hopes which the rapid progress of chemistry, and the grand discoveries relating to stone of Scheele, Wollaston, Fourcroy, and others, some time ago gave birth to, that we should be able to dissolve stone by lithontriptics, and thus save the horrors of lithotomy, had again died away, and the researches of many ingenious men who have been, and still are employed about the question, have, for their end, more to prevent the formation of stone by remedies and regimen, than to improve the manner of removing it when once formed. I trust, however, notwithstanding the supposed exhausted nature of the subject, that the following essay will prove that much was still possible in the improvement of this department of the healing art.”

The publication from which the above paragraph is taken, and the “*Treatise*” which preceded it, in both of which new instruments and new processes were described, and interesting facts were detailed, aroused the public attention in England to the possibility of improving the treatment of stone ; and about the same time, a similar spirit awoke with more decided effects in France. The results have now become of great importance to humanity. In the medical publications since



that time, cases soon began to be recorded of lithotomy superseded by new means, and lately such cases form the majority. We shall now briefly animadvert to the principal of these means, intending, however, only to interest the reader in a manner that may lead him to the perusal of the original works, where more minute information is to be found. They shall be named in the order in which they have come into use.

The *dilator*, as applied to the treatment of stone, has already been spoken of in the preceding pages.

The *double catheter*. This instrument, with its applications to cases of stone and other affections of the bladder, is described in *Arnott's Cases*. It has two channels, by one of which a fluid may pass into the bladder, while by the other there is a returning current mixed with urine. It is equipped with two pliant tubes, of which one leads from a *supplying reservoir*, and the other to a *waste vessel*. It will soothe irritation of the bladder, whether arising from stone or not, by keeping the acrid urine in a diluted state, or by applying bland and medicated liquids directly to the internal surface of the bladder. Not being larger than a common catheter, it may be worn for any period as the common catheter now is. It needs prevent no sedentary occupation, and may be used during sleep. It will act powerfully to dilate a contracted bladder, if the reservoirs be placed high, and the fluid be caused to distend with the pressure of a lofty column. It also affords by far the best means of admitting to the

bladder any solvent of stone. Even pure water is a weak solvent of most animal calculi, as is proved by placing them in a running stream; but the living bladder bears with impunity a diluted acid or alkali.

The *syphon catheter* (also first described in *Arnott's Cases*) is merely a catheter of a length that will allow its external part to descend, so as to constitute the long leg of a syphon. (See *Pneumatics*.) Its outer extremity is turned up a little, or has a portion of soft animal gut tied upon it to act as a valve, for preventing the entrance of air. The most useful application of this instrument is to keep the bladder empty after operations, until the healing process has made a certain advance. The diffusion of urine among the surrounding parts after lithotomy, particularly after the high operation, is often a cause of death; and the syphon catheter, by providing a channel by which the urine must immediately pass away as secreted, obviates the danger. This instrument is sometimes useful in very irritable bladders, by preventing the repeated distensions of the bladder, with the consequent excruciating contractions. It has also relieved in the deplorable case of the bladder torn or opened by sloughing in parturition, as it can keep the unhappy patient quite dry.

A *forceps*, calculated to pass through a tube into the bladder, and to open there, for the purpose of seizing any small stone or other solid object offered to it, was described long ago in the *Arma-mentum Chirurgicum* of Scultetus, but was again forgotten until John Hunter's investigations led

him to a second invention of it. Such an instrument had for a considerable time passed under the appellation of *Hunter's urethra or bladder forceps*, answering for extracting small stones, and therefore, if used in time, preventing occasionally the necessity of lithotomy. Soon after the publication of Arnott's Essay, it was modified and much more extensively used by Sir Astley Cooper and other surgeons in England.

But a new and intense interest has now been excited with respect to the forceps, as a means of removing stone, by the discovery—also an old discovery revived—that a *straight* tube may be passed to the bladder, as a conductor, instead of the *bent* tubes or catheters commonly used. A door is thus, as it were, opened directly into the bladder, through which a stone might even be seen, if light were directed upon it, and through which it easily may be caught and broken to pieces, and brought away without doing injury to the living parts. Dr. Civiale, of Paris, had the merit first of contriving good instruments for this operation, and of himself operating with complete success in many cases. But the praise of carrying the operation of *Lithotrity* (*stone-wearing-down*), as it is now named, to its present state of perfection, is shared by various other ingenious surgeons, as Gruithuisen (who first used the straight sound); Amussat, Leroy, Heurteloup (who proposed the mode of percussion), &c. The operator introduces a strong forceps, which seizes and holds fast the stone, and he then weakens the stone by boring it in various directions with a simple drill,

which passes through the handle of the forceps, and is turned rapidly by a drill-bow acting on its external end, or with a drill of which the point can be bent to one side, so as to excavate to any desired extent; after which weakening, the stone is crushed, either by the forceps which first held it, or by another instrument called *brise-coque*, made on purpose:—or without boring at all, Hourteloup and others at once break the stone to pieces by blows of a small hammer acting on a sliding limb of the forceps.

Dr. Darwin, in his *Zoonomia*, published in 1790, proposed to seize stones by forceps passed into the bladder, and then to break them down or destroy them mechanically; but the supposed necessity of working through a long bent tube prevented trials from being made. The author of this work also shewed, some years ago, before any of the above-described improvements were made (see *Cases*, page 93), that it was possible to pass a bag into the living bladder, and to enclose a stone there, so that any solvent might be injected into the bag, and again withdrawn without coming into contact with the bladder. This was shewn rather to excite attention to the possibility of operating within the living bladder with great precision, than to recommend that precise means of destroying stone.

To all the ingenious instruments above spoken of for breaking down the stone there is still this objection, that it is broken into such fragments, that many of them require to be afterwards treated as distinct stones, and thus the painful opera-



tion has to be repeated again and again, and whole months may pass before the operation be completed.—The author deems it possible to make a forceps of several claws or ribs, which should surround the stone so loosely as to leave it freedom of motion within the claws, like a loose kernel in a shell, and so that on making the forceps itself whirl backwards and forwards, like the drill in Civiale's apparatus, the stone might be quickly rubbed to dust by the friction or file action of the roughened interior of the claws. The bladder would be filled during the operation, with water, or even air, to secure plenty of room for the turning instrument:—or a slender external forceps might be used as a guard, to prevent contact of the bladder with the moving instrument. Out of the body, a stone harder than urinary calculus, placed in such a cage with rough interior, and subjected to the action described, is soon reduced to dust. There are various ways of making a forceps or cage for this operation, which will readily suggest themselves to persons knowing what has already been achieved in this department of practice, and having the ingenuity likely to engage them in such a pursuit.

The *high operation* of lithotomy possesses over the common *lateral operation* such advantages as the following;—thinness of the parts cut through—distance of the knife from important arteries—stones of very large size may be more easily extracted—the prostate gland is not wounded. But the high operation has not become general,—because—there was difficulty in avoiding the perito-

neum while making the opening into the bladder—there was danger of effusion of urine among the cut parts, after the operation—and where the bladder was contracted, the incision had to be very deep. Now these objections are obviated by, 1st. the *double catheter*, which will dilate the contracted bladder; 2d. by the *syphon catheter*, which will prevent the effusion of urine; and 3d. by the jointed *sliding sound* (see *Cases*, page 104), which will ensure the accurate cutting in the desired place. Had we possessed, then, for the removal of stone, no less hazardous means than cutting, the high operation with the new securities might have been the best.

When a catheter has to be retained in the bladder after any operation, in cases where, if it slipped out, it might with difficulty be replaced, something should be passed through it like a small spring forceps, to expand and become an internal button preventing its escape (see *Cases*, page 103).

#### UTERINE PHENOMENA.

Although so many of the uterine phenomena are mechanical, there are few of them which could be treated of with advantage, except in connexion with particulars, of which the consideration does not belong to a work like this. We shall however cite the following particulars as examples.

The protection given to the tender foetus by the *liquor amnii* in which it floats, is such, that a blow from without is expended on the surrounding water, and cannot reach the foetus.

The head of the foetus, because ossification be-

gins in it first, becomes of greater specific gravity than the other parts of the body, and therefore generally lies at the bottom of its liquid bed. In is thus ready to appear first in parturition, according to the safest course of delivery.

The membranes distended by the liquor amnii descend before the head, as a soft but powerful wedge preparing the way, according to the principle explained in a previous page.

We have spoken at page 348, under the name of *pneumatic tractor*, of a circular piece of leather or similar soft substance, kept extended by included solid rings or radii, as being adapted to some purposes of surgery. Now it seems peculiarly adapted to a purpose of obstetric surgery, viz. as a substitute for the steel forceps, in the hands of men who are deficient in manual dexterity, whether from inexperience or natural inaptitude. The forceps, to be well and safely used, requires address, which even the naturally dexterous man cannot possess without a certain degree of continued practical familiarity with it, and except in large towns, a man must be very unfortunate in his practice who often requires it: hence the really small number of persons who use it well. The consideration of the tractor as a substitute for it belongs properly to the present section: but as the true mode of action of the tractor is not very readily conceived, by persons who either have never been instructed in the general laws of physics, or who have ceased to be familiar with them, such persons are advised to read this paragraph in continuation of that at page 348, and to

weigh well the following remarks. A tractor of three inches in diameter, would act upon any body, to lift or draw it, with a force of about a hundred pounds—with more, therefore, than is ever required or allowable in obstetric practice. In lifting a stone, the tractor does not act as if it were glued or nailed to the stone, but merely bears or takes off the atmospheric pressure from one part, and allows the pressure on the opposite side, not then counterbalanced, to push the stone in the direction of the tractor ;—so when placed upon the head, it would not pull by the skin, in the manner of a very strong adhesive plaster applied there, as uninformed persons would be apt to suppose, but by taking off a certain atmospheric pressure from the part of the head on which it rested, it would allow the pressure on the other side or behind to urge the head forward on its way. Of course the forwarding pressure in such a case would not operate on the head directly, but through the intervening parietes and contents of the maternal abdomen. It would be much better to have a gentle and diffused action of the tractor over a large surface, than an intense action on a small surface, and therefore a tractor for the purpose now contemplated should not be very small, and should have a little air underneath it in a slight depression or cavity at its centre.—The forceps must be more effective than the tractor for rectifying malposition of the head, and diminishing its transverse diameter ; but the tractor will answer both these purposes in a degree greater than many would expect. The author proposes to publish on



this matter, and on some other strictly professional subjects which are lightly touched upon in the present general work, such a practical detail, as for the dilator, syphon catheter, &c. is found in his brother's "*Treatise*" and "*Cases*."

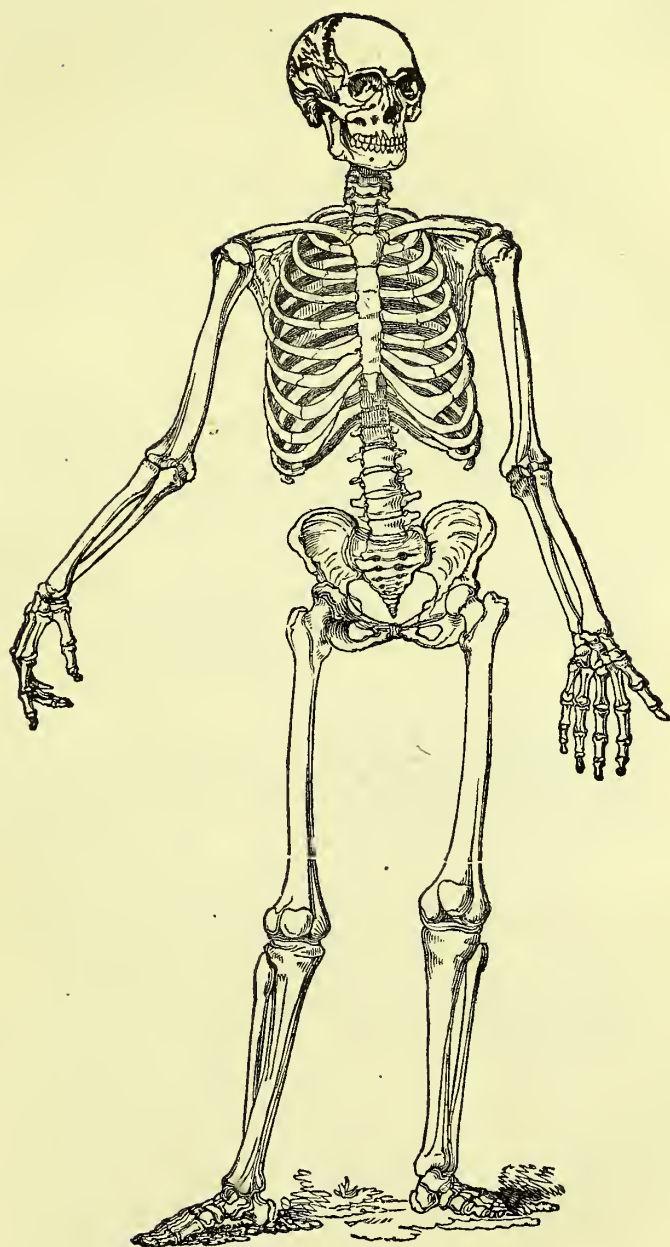
### *Conclusion.*

It is almost superfluous to remark here, that for the practice of general and obstetric surgery, learning and judgment are of little avail unless accompanied by manual dexterity: and it is one of the improvements yet to be made in our systems of education for various professions, to cultivate more methodically the use of the hands. Children and young people, in obtaining practical familiarity with ingenious toys, tools of carpentry, games of address, musical instruments, &c., are often fitting themselves for the important business of their future life.

While the author directs the attention of the profession to the important physical considerations set forth in the preceding pages, he deems it necessary most pointedly to remark, that in the living body *mechanical* principles are generally associated in their operation with the more recondite principles of *chemistry* and of *life*; and that the man who allows his mind to dwell too exclusively on any one of the three classes, must be a very bad reasoner in questions either of health or disease. It is within a very recent period, however, that just views on this subject have begun to prevail, and that the titles of the peculiarly mechanical physician, or chemical physician, or physician at-

tending only to the influence of nerves or life, are likely to be no longer justly applicable. The light of true philosophy is at last breaking in upon the very complex and difficult subjects of medical inquiry ; and where formerly keen penetration beheld only confusion, even common minds now begin to see clear divisions and beautiful arrangement.

END OF VOL. I.







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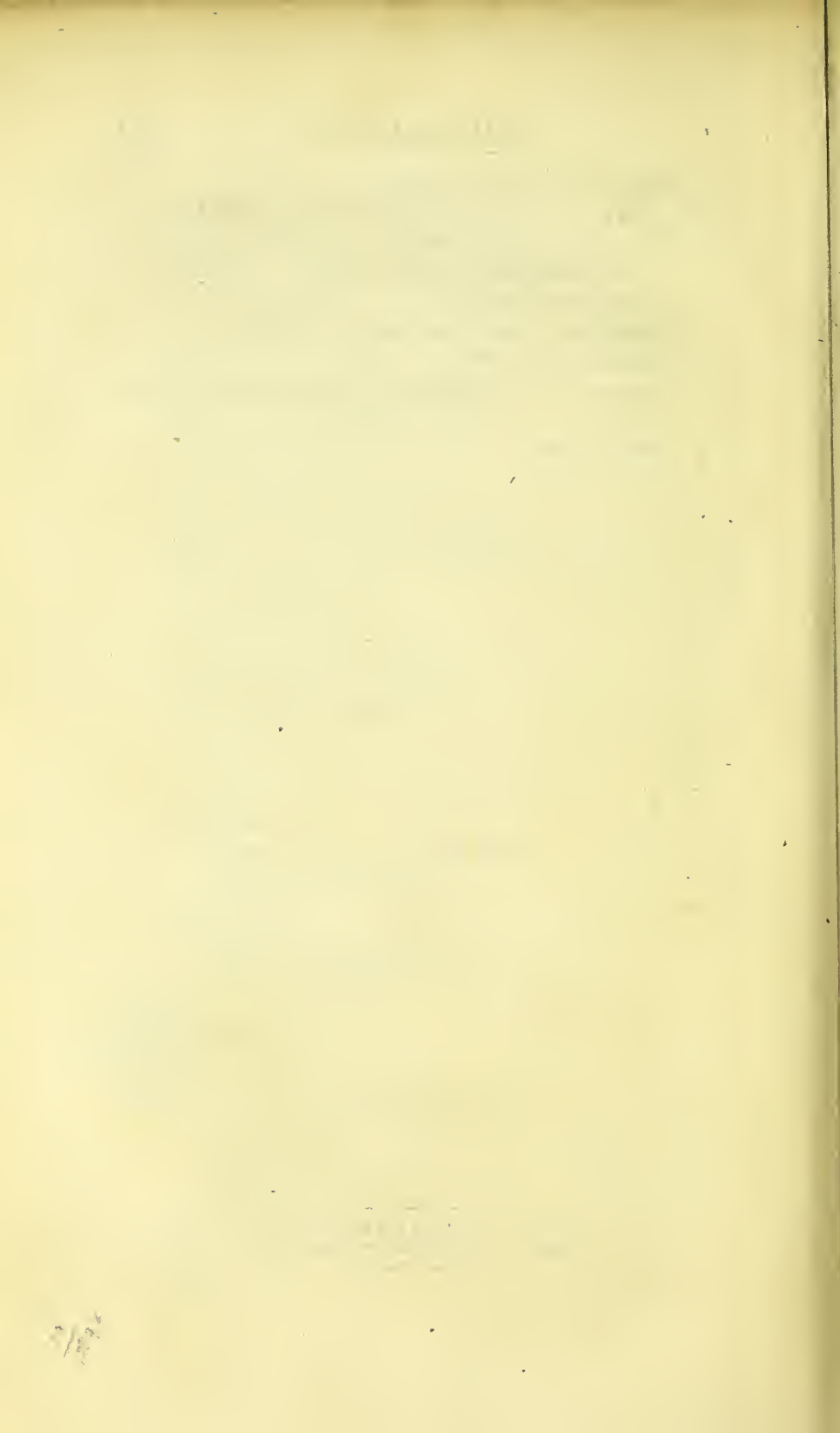
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